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THE INSTITUTION

OF

MECHANICAL ENGINEERS.

ESTABLISHED 1847.

PROCEEDINGS.

1901.

PARTS 3-5.

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24/8/03

PUBLISHED BY THE INSTITUTION,
STOREY'S GATE, ST. JAMES'S PARK, WESTMINSTER, S.W.

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PAST-PRESIDENTS.

GEORGE STEPHENSON, 1847–48. (*Deceased* 1848.)

ROBERT STEPHENSON, F.R.S., 1849–53. (*Deceased* 1859.)

SIR WILLIAM FAIRBAIRN, BART., LL.D., F.R.S., 1854–55. (*Deceased* 1874.)

SIR JOSEPH WHITWORTH, BART., D.C.L., LL.D., F.R.S., 1856–57, 1866. (*Deceased* 1887.)

JOHN PENN, F.R.S., 1858–59, 1867–68. (*Deceased* 1878.)

JAMES KENNEDY, 1860. (*Deceased* 1886.)

THE RIGHT HON. LORD ARMSTRONG, C.B., D.C.L., LL.D., F.R.S., 1861–62, 1869. (*Deceased* 1900.)

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JOHN ROBINSON, 1878–79.

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PERCY G. B. WESTMACOTT, 1882–83.

SIR LOWTHIAN BELL, BART., LL.D., F.R.S., 1884.

JEREMIAH HEAD, 1885–86. (*Deceased* 1899.)

SIR EDWARD H. CARBUTT, BART., 1887–88.

CHARLES COCHRANE, 1889. (*Deceased* 1898.)

JOSEPH TOMLINSON, 1890–91. (*Deceased* 1894.)

SIR WILLIAM ANDERSON, K.C.B., D.C.L., F.R.S., 1892–93. (*Deceased* 1898.)

PROFESSOR ALEXANDER B. W. KENNEDY, LL.D., F.R.S., 1894–95.

E. WINDSOR RICHARDS, 1896–97.

SAMUEL WAITE JOHNSON, 1898.

SIR WILLIAM H. WHITE, K.C.B., LL.D., D.Sc., F.R.S., 1899–1900.

The Institution of Mechanical Engineers.

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1901.

PRESIDENT.

William H. Maw,	London.

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Sir Lowthian Bell, Bart., LL.D., F.R.S.,	Northallerton.
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Sir Edward H. Carbutt, Bart.,	London.
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E. Windsor Richards,	Caerleon.
John Robinson,	Leek.
Percy G. B. Westmacott,	Ascot.
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T. Hurry Riches,	Cardiff.
J Hartley Wicksteed,	Leeds.

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Henry Chapman,	London.
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William Dean,	Swindon.
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H. Graham Harris,	London.
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Sir William T. Lewis, Bart.	Aberdare.
Henry D. Marshall,	Gainsborough.
The Right Hon. William J. Pirrie, LL.D.	Belfast.
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Sir Thomas Richardson,	Hartlepool.
A. Tannett-Walker,	Leeds.
John I. Thornycroft, F.R.S.,	London.

HON. TREASURER.	AUDITOR.
Harry Lee Millar.	Robert A. McLean, F.C.A.

SECRETARY.

Edgar Worthington,
The Institution of Mechanical Engineers,
Storey's Gate, St. James's Park, Westminster, S.W.
Telegraphic address:—*Mech, London.* Telephone:—*Westminster*, 264.

The Institution of Mechanical Engineers.

PROCEEDINGS.

July 1901.

The Summer Meeting of the Institution was held in Barrow-in-Furness, commencing on Tuesday, 30th July 1901, at Ten o'clock a.m.; William H. Maw, Esq., President, in the chair.

The President, Council, and Members were received in the Town Hall by the Worshipful the Mayor of Barrow, Councillor Henry Cook, J.P., and the Members of the Reception Committee.

The Mayor of Barrow said it was with very great pleasure that he, on behalf of the Corporation of the County Borough of Barrow-in-Furness, and of the Reception Committee, welcomed the Members of the Institution to the town. The whole town extended to them a most cordial welcome, and desired and hoped that their visit would be of importance to the Institution, and agreeable to the members. The present was the second occasion the Institution had honoured the town with a visit. Twenty-one years ago the Institution paid its first visit to Barrow, and the town was proud to feel and to know that that visit was so impressed upon their minds that they had determined to come a second time. Twenty-one years ago there was not so very much of interest to show the members, but they would now find that during the interval the town had progressed very satisfactorily. They were proud of their town. The hall in which they were assembled had been built since the last visit of the Institution, and he thought the members would agree with him that it was a noble building. He was only sorry it was not quite

(The Mayor of Barrow.)

complete in the matter of having a sufficiently large hall in which to entertain them, but that, he hoped, would come in after years. The Institution, on the previous occasion to which he had referred, was the means two years afterwards of inducing a very influential body of mechanical engineers from the Continent to visit the town, and he had the honour, though not Mayor of Barrow at the time, of receiving that deputation of about 80 of the most important Mechanical and Civil Engineers of the Continent. Their visit was doubtless due to the fame of the town expressed by those attending the meetings of the Institution two years previously. He believed the members, after making an inspection of the town would say that it was not an inconsiderable one. It possessed one of the finest approaches of any provincial town, namely, Abbey Road, which was ornamented with some fine villa residences on each side; and a noble building to be used as a Technical Instruction School was being erected. That would show the members that the Corporation was not behindhand in providing what was right for the instruction of the young people. Such matters, however, would be of minor interest to the members compared with the works of Messrs. Vickers, Sons and Maxim, which they were about to visit, and where they would see something which would be highly appreciated. They would also have the opportunity of visiting the Steel Works, the Railway Works, and other industrial establishments. He sincerely hoped the visit would be a pleasant one, and the weather propitious, and that what they would see would redound to the credit of the town, and prove to be of great advantage to the Institution, which was cultivating an art that perhaps conferred the greatest possible benefits upon mankind in the way of comfort, convenience, and happiness. He wished the Institution every prosperity.

The PRESIDENT thanked the Mayor most heartily for the welcome he had accorded to the members, on behalf of the Reception Committee. The welcome was no mere verbal one. The Mayor in his kind address had not only expressed in words the welcome which had by his deeds been assured to the Institution ever since the meeting was first suggested. From the moment the meeting was first contemplated the Institution had had the most cordial assistance from his Worship the Mayor, and everyone connected with the Reception Committee. If from time to time a suggestion was made which it was thought would promote the success of the meeting, it had only to be mentioned to receive the most cordial attention. In no case that he could remember had aid been rendered with more heartiness than at Barrow. He need scarcely say that these summer meetings were of very great importance and value to the Institution, but it was essential to ensure their success that they should be carried out in complete harmony with the wishes of the authorities representing the towns visited. Unless they were so carried out they must be more or less failures. In the present instance the Institution had had the most cordial assistance, and owed to the Reception Committee a very great debt of gratitude for the aid which had been given. In connection with the annual excursions of the Institution, it had always been thought desirable to have mingled with the more practical work of the meetings something which might possibly by adverse critics be called frivolity, but which he would rather call a little relaxation from more arduous labours. The beauties of the Barrow district would enable the members to carry out that relaxation in a most pleasant manner, and thanks to the arrangements which had been made by the Reception Committee, and particularly to the great aid received from the Furness Railway Company, there would be mingled with their visits to works some most pleasant excursions which he was sure the members would enjoy most thoroughly. Before the meetings were concluded he hoped to have further opportunities of expressing to the Mayor and to the Reception Committee the thorough appreciation by the members of the manner in which they had been met; he would therefore content himself with asking the Mayor to accept from him on behalf of the Institution his most cordial thanks for the welcome given to the Institution.

The Minutes of the previous Meeting were read and confirmed.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following one hundred and thirty-three candidates were found to be duly elected:—

MEMBERS.

Bailie, John David,	Leeds.
Barber, John Watkins,	London.
Carter, Edwin, Engineer R.N.,	Devonport.
Cartwright, William,	Ashton-under-Lyne.
Corbett, Alexander John,	Singapore.
Crawford, Joseph,	Belfast.
Ellis, Arthur,	Cardiff.
Fedden, Samuel Edgar,	Sheffield.
Fell, Aubrey Llewellyn Coventry,	Sheffield.
Flindt, Ernest Just,	Cardiff.
Fox, William,	Manchester.
Gearing, Ernest George,	Leeds.
Gibbons, William Gregory,	Goole.
Gordon, Alexander Grant,	Hong Kong.
Greenhill, Thomas Arthur,	Madrid.
Hartley, William Archbold,	Sheffield.
Hough, Edward Stamford,	London.
Jefferies, Harold Sellis,	Ipswich.
Keightley, Alfred Percival,	Bombay.
Little, Gilbert,	Birmingham.
Livesey, George Thomas,	London.
Loud, Henry Sherman,	London.
MaGuire, Frederick George,	London.
Miller, Fred,	Belfast.
Morris, William,	Birmingham.
Mowat, Thomas,	Aberdeen.
Münzel, Max,	Deutz.
Mutter, William,	Rangoon.
Perkins, Charles Clifforde,	London.
Redman, Joseph,	Halifax.
Reeves, Arthur Robert,	London.

Sams, Joseph Henry,	London.
Sprott, Robert Edmund,	Manchester.
Stead, William,	Manchester.
Steele, Robert,	London.
Steele, William Russell,	Howrah, Bengal.
Stormont, Peter Campbell,	Singapore.
Swinburne, William,	Melbourne.
Taylor, William,	Nottingham.
Thomson, Charles,	London.
Travers, Ernest James,	Belfast.
Tullis, David Kiel,	Glasgow.
Vaughan, John Alfred, Engineer R.N.,	Simon's Bay, S. Africa.
Walmsley, Charles,	Bury, Lancashire.
White, Robert,	London.
Whitehead, Thomas,	Manchester.
Willatt, William Henry,	Hull.
Wilton, Bartel,	Rotterdam.
Wright, Walter,	Birmingham.

ASSOCIATE MEMBERS.

Arundel, Arthur Samuel Drew,	London.
Beck, Alexander Edward,	London.
Bell, James Alexander,	Aberdeen.
Bennett, Percy Mayson,	Newcastle-on-Tyne.
Bindemann, Harry Otto Ferdinand,	Berlin.
Briggs, Ernest Reynolds,	Rugby.
Brotherhood, Stanley,	London.
Campbell, Ernest Waterhouse,	Leeds.
Carter, Frank,	Rochdale.
Clifton, William George,	London.
Close, Henry Alwyn,	Grantham.
Colbourne, Thomas Salmon,	Barnstaple.
Cole, Alfred Thomas,	London.
Cooper, William James,	London.
Couch, Richard Ernest,	Brighton.
Davies, Francis Edward,	London.

Eastlake, Arthur William,	London.
Garratt, Ernest Albert,	London.
Hamilton, Thomas Fulton,	Carron, Stirlingshire.
Hampton, Joseph,	Birmingham.
Hanning, William,	Paris.
Hatschek, Emil,	London.
Holbrow, Charles Anthony,	London.
Hummel, Horace James Jordan,	London.
James, Victor Augustus Mesham,	London.
Jones, Samuel Dawson,	Birmingham.
Keast, James Champion,	Camborne.
Kimber, Harry Watkins,	London.
Lea, Frederick Mackenzie,	Birmingham.
Lindsay, Hon. Walter,	Mertola, Portugal.
Loughborough, Charles,	London.
March, Sydney Herbert,	Manchester.
Mason, John William Victor,	Manchester.
Murray, Peter Butchart,	Dundee.
Nichols, Henry Francis,	Adelaide.
Osborn, John Lee,	Plymouth.
Oughterson, George Henry,	Barrow-in-Furness.
Parks, Walter Algernon,	London.
Parr, George Dudley Aspinall,	Leeds.
Patchett, Joseph Henry,	London.
Peregrine, William Henry,	Rochdale.
Pointon, John Edward,	Wellington, Salop.
Prestwich, John Alfred,	London.
Robinson, Leonard Leslie,	London.
Rushton, James Lever,	Bolton.
Ryder, George Albert,	Bolton.
Sawyer, Charles Payne,	Sheffield.
Shadwell, Lancelot Horace Augustus,	London.
Smeeton, John Alfred,	London.
Spiller, William Onsild,	Southampton.
Sprunt, Herbert William,	London.
Stephens, Hilliard,	London.

Stokes, John Thomas,	London.
Stones, William Grimshaw,	Blackburn.
Tatham, James Ernest,	London.
Thom, Frank,	Blackburn.
Thompson, Frederick Wilberforce,	London.
Thorpe, Wilfred Bertram,	London.
True, Robert Arthur,	Peterborough.
Walkem, George Alexander,	Vancouver, B.C.
Walker, Robert,	Bolton.
Wardle, Frank Harold,	Nottingham.

ASSOCIATE.

Mecredy, James,	Dublin.

GRADUATES.

Barnwell, Eliott Arthur,	London.
Barrs, Edward,	London.
Brown, Charles Anderton,	Oakengates, Salop.
Cliff, Thomas Percy Barlow,	Northwich.
Davson, Cyril Were,	London.
Emerson, William Alexandra Ingilby,	Doncaster.
Frisby, Archie George,	Cardiff.
Fryer, John Edwin George,	London.
Gard, George Richard,	Cardiff.
Gaskell, Holbrook, Jun.,	Liverpool.
Gough, Percy Edwin,	Cardiff.
Harden, George Fredrick St. Clair,	Chelmsford.
Haslam, Sidney Bertram,	Cardiff.
Hollingsworth, Bertram,	St. Helens.
Hussey, Frederick Kinneer Eyre,	London.
Maw, Thomas Frederick,	Gainsborough.
Newton, Percy,	Lincoln.
Purse, Frederick Walter,	Warrington.
Rouse, Frederick Robert Charles,	London.
Thomas, Nevill Senior,	Cardiff.
Walker, Thomas Archibald,	London.

The President announced that the following eight Transferences had been made by the Council:—

Associate Members to Members.

Ashford, John,	London.
Gass, John,	London.
James, William Henry,	Madras.
Johns, Cosmo,	Sheffield.
Moore, Thomas Lamb,	Belfast.
Newman, Reginald William,	Birmingham.

Graduate to Member.

Tangye, John Henry,	Birmingham.

Graduate to Associate Member.

Cleverly, William Bartholomew,	Stourbridge.

The following Papers were then read and discussed:—

"Naval Ordnance"; by Lieut. A. Trevor Dawson, of London.

"The Arrangement and Equipment of Shipbuilding Works"; by Mr. James Dunn, of London and Barrow-in-Furness.

"Barrow Docks and Approaches by Land and Sea"; by Mr. Frank Stileman, of London and Barrow-in-Furness.

At a Quarter to One o'clock the Meeting was adjourned to the following morning.

The ADJOURNED MEETING was held in the Town Hall, Barrow-in-Furness, on Wednesday, 31st July 1901, at Ten o'clock a.m.; WILLIAM H. MAW, Esq., President, in the chair.

The following Papers were read and discussed:—

"Review of Marine Engineering during the last Ten Years"; by Mr. JAMES MCKECHNIE, of Barrow-in-Furness.

"Some Work in the Development of a Motor-Car"; by Mr. M. HOLROYD SMITH, *Member*, of London.

The following Papers were also presented for publication in the Proceedings:—

"The Barrow Hematite Steel Works"; by Mr. ARTHUR J. WHILE, of Barrow-in-Furness.

"History of the Furness Railway Locomotives"; by Mr. W. F. PETTIGREW, *Member*, Locomotive, Carriage, and Wagon Superintendent, Barrow-in-Furness.

The PRESIDENT proposed the following Vote of Thanks, which were passed with applause:—

To the Worshipful the Mayor, Councillor Henry Cook, J.P., and the Corporation of Barrow, for their kindness in granting the use of the Town Hall for the present Meeting, and of the old Town Hall for the Institution Dinner.

To His Worship the Mayor for his hospitality in entertaining the Members to Luncheon in the Old Town Hall.

To the Directors and Officers of the Furness Railway Company for their kindness in providing special trains and steamers, and to the whole of the Railway Companies for other travelling facilities for Members attending the Meeting.

To Messrs. Vickers, Sons and Maxim for their hospitality in entertaining the Members at Luncheon, and for their kindness in throwing open all departments of the Naval Construction Works to the visit of Members.

To the Municipal Authorities, and to the Proprietors and Engineers of Mines and Works, for the arrangements they have kindly made to receive the Members at their respective establishments.

To the Reception Committee, especially to the Conveners, His Worship the Mayor, Chairman, and Mr. James Dunn; and to the Honorary Secretary, Mr. Archibald Miller, for their valuable advice and aid in maturing the arrangements.

To the Hodbarrow Mining Co., The Millom and Askam Hematite Iron Co., and Messrs. John Aird and Co., for their kind invitations to Luncheon at Furness Abbey Hotel, and for arranging the visit to the Mines at Hodbarrow and to the Sea Wall and New Outer Barrier at Millom.

The Meeting then terminated at a Quarter to One o'clock. The attendance was 249 Members and 63 Visitors.

NAVAL ORDNANCE.

By Lieut. A. TREVOR DAWSON, of London.

Naval ordnance embraces most of the branches of the science of which the mechanical engineer is the master, and has this further importance, that upon its effective application to our fleet the Empire depends for supremacy, independence, almost for existence. It is true that there are other elements necessary to the fighting efficiency of a warship—speed, invulnerability, and radius of action; but these vary according to the duty the ship has to perform, and with our vast Empire marching the territory and touching the susceptibilities of almost every Power, such duties are many. Gun power however must always be a dominant factor; there is only one class of naval ordnance suitable, and that must be the best obtainable for the purpose, irrespective almost of financial considerations.

The urgent lesson taught by recent naval warfare is the clamant need for quick-firing, high-powered guns, well protected by armour of the highest resisting quality. There is no need to enforce the importance of long range; any ship with this advantage can "play" with a better, or equally, armoured vessel having artillery of less power: and as to gun protection, it may be recalled that when the American ships attacked Cervera's fleet in their ill-fated rush from Santiago, the Spanish crews were driven from their gun positions by a hail of 1 and 2-pdr. shot, while the ships and their deck structures were pounded by the 6-inch quick-firers and the larger breech-loaders of their opponents. Had the Spanish gun positions been adequately protected, and their gunners enabled to continue fighting their weapons, there would have been a less one-sided contest. It is of vital importance, therefore, to consider the rapidity of fire and power of guns of several of His Majesty's ships, which, although constructed only a few years ago, are deficient owing to the recent great increase in the energy of guns. It is impossible to re-design these cruisers, but new guns of greater power and a higher rate of fire could easily be fitted at little cost, adding greatly to the fighting efficiency of the ships. Probably one of the most hopeful auguries is found in the fact that Rear-Admiral May, who did such splendid service to the Navy by his experimental and research work in the gunnery ship "Excellent," is now Controller of the Navy in succession to Vice-Admiral Wilson, who himself introduced so many improvements into the service.

As an instance of the inferiority in gun power of some of our comparatively new cruisers, a comparison is made on Table 1 of the aggregate energy of the guns of H.M.S. "Diadem," which was launched in 1896, just five years ago, and of H.M.S. "Hogue," practically of the same size, now being fitted out at Vickers' Naval Construction Works at Barrow-in-Furness. The basis of comparison is the most accurate one of the striking energy which the guns develop, when utilised to the best advantage in a given time. For this comparison the velocities of the 6-inch gun of the "Diadem" and "Hogue" are assumed to be respectively 2,150 and 2,550 feet per second, giving energies, at 3,000 yards range, of 1,416 foot-tons and 1,996 foot-tons, and the velocity of the 9·2-inch gun is 2,720 feet per second, representing an energy of 11,564 foot-tons at 3,000 yards. The rapidity of fire obtained is indicated in the Table. The 12-pdr. guns and those of less calibre are not included, as their power in determining the issue of an action at long range would be small. The result of the comparison is that the total striking energy of the "Hogue" is almost double that of the "Diadem"—296,516 foot-tons against 158,592 foot-tons. This surely is a condition which calls for consideration, especially as it is but a fair representation of the increase in the power of the guns of today, and at this early point in the review of the whole question the author would like to associate the firm of Sir W. G. Armstrong, Whitworth and Co., as well as Vickers, Sons and Maxim, with the great advance made in recent years in all departments of ordnance.

TABLE 1.

Total Energy per minute of the Guns in two Cruisers fighting at 3,000 yards range.

On 1st Class Cruiser "DIADEM" launched in 1896.	On Armoured Cruiser "HOGUE" launched in 1900.
16 6-inch guns with a muzzle velocity of 2,150 f. s., and firing at the rate of seven rounds per minute, will give a total energy—158,592 foot-tons.	12 6-inch guns with a muzzle velocity of 2,550 f. s., and firing at the rate of nine rounds per minute, will give an energy of 215,568 foot-tons.
	And
	2 9·2-inch guns with a muzzle velocity of 2,720 f. s., and firing at the rate of 3½ rounds per minute, will give an energy—80,948 foot-tons.
TOTAL ENERGY—158,592 foot-tons.	TOTAL ENERGY—296,516 foot-tons.

This comparison is made on the assumption that the Service explosive—namely, cordite—is utilised; if, however, nitro-cellulose powder were used in the more modern guns of H.M.S. "Hogue," which are equally well designed for its use and would have a much longer life, notwithstanding the increased energy, the twelve 6-inch guns would then have a velocity of 2,800 f. s., and, firing at the same rate, would give an energy of 259,740 foot-tons; and the two 9·2-inch guns would have an energy of 91,966 foot-tons, firing at the same rate and with a velocity of 2,900 f. s. The total striking energy of the "Hogue" would thus become 351,706 foot-tons, as against 158,592 foot-tons of the "Diadem"—a condition which can easily be realised when manufacturers are given the necessary orders.

The progress indicated in Table 1, it is significant to note, is not confined to British ships; more importance, perhaps, is given to the subject of war material by the general public in the United States, France, Germany, and perhaps Russia, than by the people of Britain, notwithstanding the fact that our responsibilities are immeasurably greater and that the weakening of our sea power must tend to seriously imperil the position of our great Indian Empire, the Dominion of Canada, the Commonwealth of Australia, and the other Colonies. As an instance of this, it may be mentioned that the great forges and steel works at Creusot, St. Chamond, Chatillon, Commentry, and other works abroad, have in the last three or four years more than doubled their productive capacity, and are now working at the highest pressure, while in this country men are being discharged from the great factories where ships, guns, and other munitions of war are made. Public opinion abroad really insists on all the great firms being kept continually and fully employed, in order to keep pace with the shipbuilding programmes of maritime contemporaries.

THE STRUCTURE OF GUNS.

But within this Institution we are engineers, although none the less loyal citizens, and therefore we are interested more in the mechanism than in the political effect of ordnance. And first, attention is directed to the structure of guns. On Plates 63 to 67 there are illustrated for general purposes of comparison various types of British and Foreign guns of strictly modern design. Two general systems of construction are adopted by most naval Powers—in the one the gun is entirely of steel and in the other of steel and wire. Great stress cannot be laid on the advantages of the one system over the other. At the same time the author is of opinion that, by the proper application of wire, the highest possible efficiency in construction can be obtained owing to the greater possibility of varying the tension of the wire and tubes with greater theoretical accuracy than is possible with solid steel construction. Steel as wire is much the strongest form of this metal. Moreover the wire winding gives higher resisting radial strength to the gun, and this is of great value in the event of a premature bursting of a high explosive shell in the bore. On the other hand, the wire-constructed gun is more expensive in manufacture, but this is not of much consequence provided the best results are obtained.

The Wire-Wound Gun.—The diagram of the 12-inch 40-calibre gun of British type, Fig. 1, Plate 63, clearly shows the construction of a typical wire-wound weapon, and the disposition of the wire and tubes and other general details; there are added curves showing the pressures in the bore on the explosion respectively of nitro-cellulose and cordite charges. This method of construction —with one tube inside another, extending the whole length of the gun—admits of rapid and efficient repair when the inner tube is worn out as a result of a number of rounds having been fired. The radial strains on firing are overcome by the shrinkage of the A tube of the gun upon the inner tube, and by the wire being wound at varying tensions. The longitudinal strains are taken by the large sections of the A tube and jacket being connected by a breech ring. The construction of this gun is practically similar to the 7·5-inch 45-calibre gun shown on Fig. 3, Plate 65, where also dimensions and curves of pressure are included.

Other general types of wire-constructed guns are shown by Fig. 2, Plate 64, illustrating the 9·2-inch B. L. gun designed and constructed by Messrs. Vickers, Sons and Maxim, for the Turkish Government, and by Fig. 4, Plate 66, showing the 6-inch 50-calibre gun now being manufactured by the same firm for the Japanese Government. It will be seen by reference to these diagrams, Figs. 2 and 4, that the wire only extends for about one-half the length of the shot travel, the radial strains in the chase being taken by a solid steel hoop shrunk over the inner tube. In guns of 50-calibres length the elimination of the wire over the chase enables the girder strength to be somewhat improved, so that there is no fear of the extra length causing the gun to droop.

The Steel Constructed Gun.—A general type of steel constructed gun is shown in the diagram, Fig. 5, Plate 66, illustrating the 14 cm. 45-calibre gun supplied by Vickers, Sons and Maxim to the Spanish

Government. It consists of an inner and outer A tube extending the whole length of the gun, reinforced by a jacket and breech ring. The inner is put into the outer A tube with a taper of 1 in 500, with a suitable amount of shrinkage to ensure the best constructional effects.

Nickel Steel versus *Wire Winding.*—Messrs. Krupp, who have done so much for the improvement of ordnance generally, use nickel steel for all the tubes except the inner. The use of nickel steel, instead of ordinary steel, has no doubt some advantages, notably greater strength of material, but this high quality of steel is not so necessary with wire-wound guns, owing to the extra strength given by the wire far exceeding that of any ordinary nickel steel. The author is much in favour of using a steel giving a high elastic limit and good elongation for the smaller types of guns, for which the wire system is perhaps less suited. By using suitable steel and treating it by a special process, the necessary strength can be obtained without the addition of nickel.

The Construction adopted with Small Guns.—Another type of steel gun to which reference may be made is the 14-pr. automatic quick-firing gun adopted by the United States of America, illustrated by Fig. 6, Plate 67. The small charge used by this gun does not render it imperatively necessary to reinforce the chase, but the A tube of the gun is made of the best quality of steel and suitably treated to perform its proper functions. The jacket of the gun, which also carries the mechanism, is shrunk on from the breech end and is locked to the A tube by a second hoop. This construction is largely adopted for guns of small calibre, and is especially applicable where the breech block works in the vertical plane.

THE BREECH BLOCK AND OBTURATOR.

The systems of breech loading utilised with modern naval artillery are very varied, but may generally be divided into two:—

Firstly, those utilising screw mechanisms, in which the longitudinal strain on firing is conveyed through the breech screw to the outer construction of gun, the gases being sealed by some well-known device; and secondly, the wedge- or block-form of mechanism, in which the longitudinal strain on firing is taken up by a block of steel of general construction worked by some suitable mechanism for opening or closing the breech, the gases being sealed by means of a metallic case.

The wedge system of mechanism is that generally adopted by Messrs. Krupp, although they also utilise the breech screw system in some of their guns.

Screw versus *Wedge Plug*.—The only serious advantage which can be claimed for the block or wedge type of mechanism is that, generally speaking, it is simpler in construction, but it necessitates a continuation of the gun tubes beyond the breech end, and, as this projection is otherwise non-effective, the extra weight counterbalances the advantage of simplicity. The wedge system has been adopted generally in Germany and Austria, and many of the smaller countries of Europe and South America. The breech screw form is much more generally utilised, having been accepted by Great Britain, France, the United States, Russia, Spain, Italy, &c. Indeed it may be considered the best form of breech closing device at present in use, and its general features may be referred to.

The design of the screw mechanism depends principally on whether it is desired to utilise a metallic case obturator or the plastic pad system. In both cases, however, the form of breech screw used is to a great extent a governing factor, and is of great importance. The type of screw invented by Mr. Axel Welin, a Swedish engineer, is the one at present mostly used in modern artillery mechanisms, the British Government having generally adopted it, as well also as the United States of America, while several other countries have equipments now under experiment. It is shown in Fig. 7 (page 510). The construction of the screw is such that, in the case of the 12-inch mechanism, three-quarters of the circumference can be utilised as threaded surface, leaving one quarter only non-effective for taking up the backward thrust due to the explosion of the propellant in the gun chamber. In the case of the 6-inch breech plug two-thirds of the circumference can be screwed, and one-third only is thus non-effective. The length and weight of the plug for a given resistance can thus be reduced, effecting a still greater saving in the weight of metal at the breech end of the gun, while there is great advantage in the general arrangement of the mechanism owing to the shorter screw. The author has experimented with this screw in connection with a 15-pounder field-gun, firing the gun with the breech rather more than half open; the portion of the screw in bearing (rather less than half the ordinary shearing section) proved sufficient to hold it in place even under proof pressure, and no damage to the mechanism resulted. This experiment showed the great strength, utility, and efficiency of this form of screw, while great saving in weight is effected. Thus the breech screw of the 6-inch gun of this improved type, Fig. 7, weighs 116 lbs.; the parallel screw for the same calibre gun, Fig. 8, weighs 178 lbs., and the type of screw partially coned and partially parallel, for the same strength, Fig. 9, weighs about 212 lbs. The saving effected in the Welin form over the ordinary parallel form, is at least 35 per cent. in the breech screw alone, and a great deal more in the annulus of steel forming the rear portion of the gun into which the screw gears. A long series of experiments conclusively proved that this form of screw is the best at present utilised for breech mechanisms, either of the De Bange obturator type or of the more usual form of metallic case system of obturation.

Comparison of Breech Plugs for 6-inch Guns.

Fig. 7.
Vickers' Block.
116 lbs.

For End view, see Fig. 17, Plate 72.

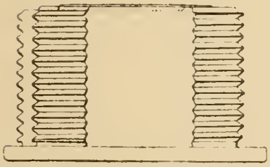


Fig. 8.
Parallel Screw.
178 lbs.

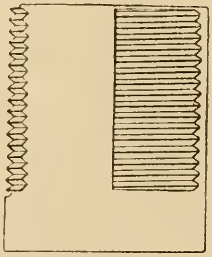
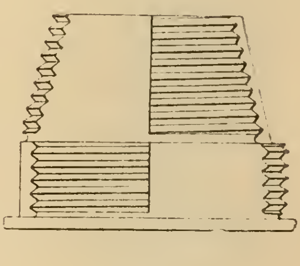


Fig. 9.
Coned and Parallel Screw.
212 lbs.



Metallic versus *Plastic Pad Obturation, etc.*—A discussion of the advantages of one system of obturation over another must necessarily be of a very technical character, and might of itself form the subject of a special Paper; it can only be briefly referred to here. In guns making use of a metallic case system, the weight of the case is a very serious objection, especially when using the very large charges required to obtain the highest possible ballistics imperatively necessary in connection with modern artillery. In order to obtain a velocity of, say, 2,900 feet per second in a 6-inch gun, a charge of powder has to be used of from 30 to 35 lbs., according to the nature of the explosive. Such a charge entails the use of a very large case, whose weight is equal to that of the charge. Now if it be assumed that for each 6-inch gun on board ship there would be 200 charges, the cases alone would weigh rather more than 3 tons per gun. In the "King Alfred" class of cruiser, there are sixteen of these guns on board, so that the aggregate addition to weight for cases alone is 48 tons. It is true that as a result of the great skill and unique experience in warship design of Sir William White, the Assistant Controller and Director of Naval Construction, our ships attain higher speed for a given power than any other warships, being exceptionally fine models, and that for a given displacement better compromises are made with the conflicting elements of design; but the artillerist ought not to demand any addition to load which is ineffective where weight is all-important. There is, moreover, the other serious disadvantage with the metallic case system of having to extract the heavy and cumbersome case from the chamber after each shot is fired, and of storing it or throwing it overboard. The objections to the case system are:—(1) The rate of fire is considerably reduced owing to the necessity of handling very heavy cartridges and of withdrawing the case after firing. (2) There is a chance of failure of the case which, when it occurs, puts the gun out of action. (3) The extra weight necessary to be carried on board ship.

All these disadvantages are overcome by the use of a suitable plastic pad form of obturation, an efficient type of which has been evolved, after much experiment, by Messrs. Vickers, Sons and Maxim. As a result of its use the 6-inch gun under the most favourable conditions attained a rate of fire of eleven rounds per minute, and with the 7·5-inch gun, firing a 200-lb. shot, a rate of fire of 8 aimed-rounds per minute. The range was 1,100 yards, and all the shots struck within a metre square of the target. Such results have never been obtained with mechanisms entailing the use of the case system of obturation, and the author has no hesitation in pressing upon general notice the great advantages obtained by the quick-firing plastic pad system of obturation. The system is equally applicable to guns up to the largest calibre, and a rate of fire of 1 round every 15 seconds has been obtained with this form of mechanism with a 9·2-inch gun, which, starting with the gun loaded, means 5 rounds for the first minute of firing. Similar rates of fire from all heavy artillery on board ship would have such a moral effect as to influence the final issue of an engagement.

BREECH MECHANISM.

There are several features common to the breech mechanism of the 12-pounder 3-inch gun, 6-inch quick firer, and the 9·2-inch and 12-inch breech loader which are illustrated on Plates 68 to 73. The mechanism is of the Vickers single movement type, whereby one motion of a hand-lever or band-wheel performs the separate actions involved in the opening or in the closing of the breech. The one action locks or unlocks the breech plug, swings it in or out of the gun, and in opening and closing actuates the firing gear. In all cases the breech block is of the Welin type, and is mounted upon, and free to turn on a carrier pivoted at the right-hand side of the breech. The breech plug already described, Fig. 7 (page 510), because of its shortness, can be swung clear of the breech without longitudinal travel or curvature within the breech. The details of the mechanism for effecting the opening or closing of the breech differ slightly in each case, and even although it involves some little repetition, descriptions of each are given.

Breech Mechanism for 12-*pounder Q.F. Gun.*—In the breech plug for the 12-pounder 3-inch quick-firing gun, illustrated on Fig. 10, Plate 68, there are six segments, and four are threaded, that is, two-thirds of the circumference is used for resisting strains.

The mechanism for actuating the breech plug A, consists of a link B, one end of which is pivoted on a pin D, projecting from the rear end of the breech plug A; the other end is pivoted to a short crank C, and pivoted on a bolt E, which may be quickly withdrawn when dissembling mechanism. Skew gear teeth are formed partly round the periphery of the crank engaging with skew teeth formed partly round the axis of the hand-lever G. This hand-lever G lies close to gun, and is so mounted that it may be quickly assembled or removed. The centres of the link B, and crank C, are arranged to form a locking point when the breech is closed.

The firing gear, which is arranged for percussion and electric firing and may be removed as one piece, is contained in a central hole formed through the stem J, of the carrier F. It is retained in position by a cap M, with interrupted threads fitting into the rear face of the carrier F. The rear part of the cap M is fitted with a sleeve, this sleeve having inclined planes formed on it, so that a partial rotation of the sleeve causes the striker R to be drawn back clear of the firing primer on the first movement of the hand-lever to open the breech. The partial rotation of the sleeve is effected by a stud O, projecting from it, and engaging with a cam groove N, formed on the top of the hand-lever G. When the sleeve has been turned to a sufficient extent, the hand-lever swings clear of the stud O. The sleeve is retained in position by a sliding bolt acted on by the turning of the breech screw A. The striker R is cocked by hand for percussion firing, and a safety piece P, in the rear face of the breech screw, prevents the striker from being released until the breech is completely locked.

A powerful extractor Q is used, which extracts and ejects the empty cartridge case. This extractor is pivoted at the same side of the breech of the gun as the carrier F, and is fork-shaped, the arms of the fork being approximately concentric with the cartridge case. The arms of the fork are provided with lips for ejecting the empty cartridge case. A third lip is formed in the bottom of the fork for unseating the cartridge case. This third lip is arranged, with respect to the lips on the arms of the fork, so that it comes into action first. A toe or third arm of the extractor Q is acted on by a cam surface (formed on the carrier F) during the last part of the swing-out when opening the breech.

The action of this extractor Q is as follows:—When the breech has been partly swung open, the cam surface on the carrier exerts a wedging action on the toe of the extractor, gradually unseating the cartridge case before the lips on the fork of the extractor Q come into action, and just immediately before the mechanism is completely swung out the toe of the extractor receives a sudden jerk, which causes the empty cartridge case to be completely ejected from the breech by means of the lips formed on the fork of the extractor. No small screws are employed, and no tool is required for use with this mechanism.

Breech Mechanism for 6-inch Q.F. Gun.—The breech plug for the 6-inch quick-firing gun, illustrated by Fig. 11, Plate 69, and perspectively by Figs. 16 and 17, Plate 72, is divided, so far as the threaded portion is concerned, into six segments, and four of these are threaded, so that in this case also two-thirds of the circumference is used for resisting the strains.

The link for actuating the breech plug is pivoted to a pin G projecting from the breech plug B at one end and pivoted at the other end to a short crank H, which is mounted on the carrier D. Partly around the boss of this crank H are formed skew-gear teeth which gear with skew teeth formed around a sleeve keyed to the hand-lever. A loading tray I is provided, which is automatically moved across the breech face of the gun and at the same time raised into the loading position while opening the breech (or lowered when closing it).

The firing gear is arranged for firing by electricity, or percussion, and is directly operated by the hand-lever A, so that the gun is absolutely safe against firing before the breech commences to open. For this purpose a nut K is fitted on the end of the obturating bolt L. In this nut a vertical slide M, which covers the end of the firing primer N, is worked by means of two spring bolts. One of the these bolts O engages with a cam P, on the hand-lever A, the other Q, in a groove R, in the link of the breech mechanism. An ejector S, actuated by the movement of the slide is fitted in the nut. A spring retaining catch is fitted in the obturator bolt and prevents the tube from being jerked out, however violently the mechanism may be closed.

The motion is as follows :—When the hand-lever A of the breech mechanism is swung away from the gun, the cam P forces the slide M downwards in the nut K. As the hand-lever A continues to swing away from the gun, it eventually loses its connection with the spring bolt O of the slide M, and the downward movement of this slide is continued by the movement of the link F, which actuates the other spring bolt Q, and keeps the slide M in the correct relative position until the breech is closed. When the slide M has been moved down far enough, it actuates the ejector S, thus jerking out the firing tube. On the first movement of the slide M downwards, and before the breech has commenced to unlock, the firing needle C is partly drawn back by means of the toe with which it is provided, engaging with a quick incline on the rear of the firing gear nut. The spring bolts are arranged so that in the case of misfire the slide M may be pulled down by hand to a certain extent, sufficient to eject the tube without it being necessary to open the breech.

Breech Mechanism for 9·2-*inch Breech-Loading Gun.*—In the case of the 9·2-inch breech-loading gun, as shown in Fig. 12, Plate 70, and perspectively on Figs. 13 to 15, Plate 71, the threaded portion of the breech plug B is divided into twelve segmental portions of varying radii, and nine of these are threaded, so that here three-quarters of the circumference is used for resisting the strains when firing.

As with the 6-inch gun the mechanism for actuating the breech plug B consists of a link F, one end of which is pivoted on a pin G, projecting from the rear end of the breech plug B, the other end is pivoted to a short crank H, which is mounted on the breech plug carrier C. Around the boss of a pinion I are formed skew-gear teeth. This pinion is keyed to the axis of the hand-lever A, and is contained in a recess in the carrier C. The skew teeth so formed gear with skew teeth formed on the boss of the short crank H. The hand-lever A lies close up to the gun, and the centres of the link F and crank H are arranged to form a locking point when the breech is closed.

The firing gear D is arranged for firing by electricity or percussion, and is operated so that the gun is absolutely safe before the breech commences to unlock. For this purpose a nut K is fitted on the end of the obturating bolt L, in this nut a horizontal slide M covers the end of the firing primer N, and is worked by means of a spring bolt O, which engages with a sliding bar P, working in the face of the carrier C. The sliding bar P is also provided with a spring bolt Q, which engages with a cam R on the crank H. An ejector, actuated by the movement of the slide M, is fitted in the nut K. A spring retaining catch is fitted in the obturating bolt L, and prevents the tube N from being jerked out however violently the mechanism may be closed.

The action is as follows:—When the hand-lever A of the breech mechanism is swung on its pivot to open the breech the crank H begins to move, and by means of the cam R it forces the slide M in the nut K away from the primer N. When the slide M has been moved away far enough it actuates the ejector, thus jerking out the firing tube N. From this point the action is the same as in the corresponding action of the 6-inch gun mechanism previously described.

Breech Mechanism for 12-*inch Breech-Loading Gun.*—The breech mechanism for the 12-inch gun, which is shown perspectively in Figs. 18 and 19, Plate 72, and in detail on Fig. 20, Plate 73, is so arranged that the whole of the breech action is operated and controlled by the rotation of a hand-wheel. By turning the hand-wheel A the breech plug B is first rotated and unlocked, and then swung out of the breech of the gun. The breech plug is mounted and free to turn on a carrier L, pivoted at the right-hand side of the breech. The threaded portion of the breech plug is divided into twelve segmental portions of varying radii, and nine of these are threaded, so that here, as in the 9·2-inch gun, three-quarters of the circumference is used for resisting the strains when firing. The obturator M is of an improved De Bange type. This improved obturator is also used in the 6-inch and 9·2-inch gun mechanisms.

The mechanism for actuating the breech plug B consists of a link C, one end of which is pivoted on a pin D projecting from the rear end of the breech plug B; the other end is pivoted to a short crank E, which is mounted on the breech-plug carrier L. Around the boss of the crank E are formed skew-gear teeth, engaging into similar teeth formed partly round the boss of a quadrant F, which is mounted in the carrier L on a vertical pivot. This quadrant F has also formed partly round its periphery ordinary spur teeth, which engage with similar teeth on a second quadrant G, fixed on the hinge bolt H of the carrier L. The hinge bolt H, together with its quadrant G, is revolved by means of a worm I and a wormwheel K, which are in turn actuated by the hand-wheel A, mounted at the breech of the gun. To open the breech the hand-wheel A is rotated, and thus, by means of the wormwheel K, the quadrant G causes the quadrant F and crank E to turn, thus rotating the breech plug B until it becomes unlocked.

By continued turning of the hand-wheel A, the carrier L with the breech plug B is swung out clear of the breech of the gun. The opposite action takes place on closing the breech.

As in the case of the 9·2-inch breech-loader and 6-inch quick-firer, the gun is arranged to be fired by electric or percussion tubes. For this purpose a nut N is fitted on the end of the obturating bolt O. In this nut a horizontal slide P, which covers the end of the firing primer Q, is worked by means of a spring bolt R, which engages with a sliding bar S working in the face of the carrier L. The sliding bar S is also provided with a spring bolt T, which engages with a cam U on the crank E of the toggle joint. An ejector, actuated by the movement of the slide P, is fitted in the nut N. A spring retaining-catch is fitted in the obturating bolt O, and prevents the tube from being jerked out however violently the mechanism may be closed.

The action is similar to that in the 9·2-inch gun previously described.

THE MOTIVE POWER FOR WORKING LARGE GUNS WITHIN TURRETS OR BARBETTES.

Hydraulic versus *Steam, Air, and Electric Motive Power.*—The mounting for the gun is as important as the gun itself or as its breech mechanism, because upon the efficiency of the mounting the rate of fire depends. The structure, while extremely mobile, must be sufficiently strong to transmit to the ship the strains that result from the enormous energies developed when the gun is fired. The rapidity and accuracy of aimed-fire are controlled to a large extent by machinery —the elevating and training-gear, the means of supplying the gun with projectiles and powder, the hoist, the rammers, etc. The motive power by which this machinery is operated considerably influences the general efficiency of the mounting, and on this point there is much difference of opinion. This is one of the several questions where the varied experience of the mechanical engineer can assist the ordnance designer. Varying circumstances affect the general rules, and necessitate special divergence from any principle laid down ; but the author is much inclined in favour of hydraulic power for the general operation of the mounting, in preference to electricity, compressed-air, or steam.

Steam Power.—For sea service it is very important to avoid any system which will cause the lower deck and compartments in the ship to become heated, especially as there is usually great difficulty in ventilating such places to make them habitable. Steam-engines with their pipe leads, valves, etc., which must radiate much heat, are impracticable from this cause alone; but in addition to this disadvantage, they are next to impossible inside a turret, owing to the danger of the gunners being scalded in the possible contingency of joints being damaged or pipes broken in action. Again, in consequence of the intermittent nature of the work done there is likelihood of failure owing to the steam condensing in the cylinders and steam leads. This might be overcome by a properly designed system of draining, but it would add complications.

Compressed-Air Power.—Compressed air has one great advantage in comparison with steam—no return pipe system is required, as all machines may exhaust into the atmosphere, and by so doing will materially assist in the ventilation of the turret. The noise, however, made by the free exhaust is very objectionable. Compressed air, to be economical, must be worked at a very high pressure, and a damaged pipe might therefore cause an explosion with serious results. Air-compressing engines are usually run at a high speed, and necessitate the employment of gear trains—a condition extravagant and noisy.

Electric Power.—Electricity, when compared with steam and air, has many advantages; no pipes are required, the conductors are extremely light as compared with the pipes which they would displace, and they can be led anywhere. On the other hand, there are a number of serious disadvantages involved. All electric motors of reasonable weight and size for the purpose must run at a very high speed, necessitating heavy gear trains, which involve much loss of power and a great deal of noise. Difficulty, too, is frequently experienced in discovering the cause of failure which occasionally occurs either in the motor, controllers, or conductors. Special safety cut-outs are required to prevent motors from over-heating. It is also practically impossible to utilise electricity for running heavy guns back to the firing position after recoil. In training and elevating by electricity, great difficulty is always experienced in getting dead-slow movements to enable the gun to be perfectly sighted on the target. Many devices have been introduced to overcome this drawback, but none have proved quite satisfactory; an electric motor can scarcely be started at slow speed. Again it is generally stated as one of the advantages of electric over hydraulic power that if a wire breaks, it is more easily repaired. This, however, is not the experience of the author, as it has often proved most difficult to detect quickly a short or broken circuit. With hydraulic power the escape of water is certain and is easily discovered, and, since the introduction of flexible piping, a broken pipe is quickly repaired by replacing the whole piece between the two stop-cocks.

Hydraulic Power.—Hydraulic power has practically none of the disadvantages enumerated for the other systems of power described. Pipes can be laid anywhere, they give out no heat, if they are damaged no explosion takes place, and the damage can easily be discovered and quickly repaired. Hydraulic machines can in most cases be applied direct for elevating, running out and in, lifting ammunition, and for hauling projectiles, etc., in the shell rooms and other parts of the ship. They work practically in silence. The vertical and horizontal running of the gun is under perfect control, the dead-slow movement required being obtained with the greatest facility and precision.

For sea service the source of the hydraulic power on board ship is usually a pumping-engine, so designed as to obviate the necessity for an accumulator. One engine is fitted for each turret and placed in a compartment below the armour deck, the arrangement of valves being such that either or both can work any or both of the mountings. These engines are of the compound tandem type, each with four cylinders and two pumps placed in line. They are provided with speed and pressure governors to admit of variations in the speed from 3 to 110 revolutions per minute, with pressures within 1,000 and 1,100 lbs. per square inch. The pumps are single-acting for suction work, double-acting for delivery. Large tanks built into the ship are provided for storing fresh water, in which there is a slight admixture of soft soap and oil for the lubricating of internal surfaces. Salt water may be used in an emergency, but this is not commendable. Duplicate sets of piping are provided throughout the ship. To keep down weight these are usually made of manganese bronze, a material of about twice the strength of the copper formerly adopted.

GUN MOUNTINGS.

After due consideration has been given to strength and adaptability, the principal point in the general arrangement of gun mountings, as in the mechanism of the gun itself, is to attain the highest possible aimed rate of fire. This indeed is the dominant consideration in the designing of all Vickers' gun mountings, and the attainment of this desideratum is established by reference to the illustration on Plate 74 of the mounting for two 12-inch breech-loading guns installed in several British first-class batteships. The distinctive feature of the arrangement admits of the gun being loaded at any angle of elevation, and the loading is quite independent of the laying of the gun. In earlier types it was necessary after the gun was fired to elevate it again to a fixed angle in order to re-load. This not only threw the weapon off the line of sight but took quite an appreciable time to perform, reducing the possible rate of aimed fire in a given time.

In British ships the 12-inch guns are invariably mounted in pairs, and the arrangement illustrated by Plate 74 admits of four rounds being fired from each barbette, or at the rate of 149,241 foot-tons per minute. With guns of this calibre it would seem desirable to always mount them in pairs so that, if the range is not found quite correct with the first projectile from the one gun, there is immediate opportunity of rectifying the error discovered, and thus the gun layer will seldom fail to hit with the second shot. It is the case over again of the ordinary double-barrelled gun; if you miss with one barrel you always have a second: in the case of the battleship if you hit with the first gun the chance is you will also hit with the second.

Vickers Barbette Mounting for two 12-*inch B.L. Guns for British Service.*—In the Barbette mounting for two 12-inch B.L. guns of the British type, illustrated by Fig. 21, Plate 74, the guns are mounted on a turntable, carried on a live roller-ring, and are protected by an armoured shield secured to the upper surface of the turntable. The following is a detailed description:—

The turntable A is built up of steel plates and angles, and is provided with suitable machined surfaces for the attachment of the brackets supporting the gun mountings and for the upper roller path *a* secured to its lower face. The lower roller path *b* is fixed to a structure separate from and within the barbette wall, and thereby will not be affected by any distortion of the latter.

The shell chamber C is attached to the under side of the turntable, and revolves with it.

The trunk D is attached to the floor of the shell chamber and revolves with it and the turntable.

The rollers B are provided with flanges at both ends to take the horizontal thrust, and are bound together by a ring to which the roller axles are secured.

The training rack E is attached to the turntable, and gears with the training pinions *e* which are actuated from below.

The turntable is arranged to be rotated either by hydraulic or hand power, and provision is made so that only one form of power can be in operation at the same time. For training by hydraulic power two three-cylinder hydraulic engines F are provided, which may act either in conjunction or separately; they are situated in a compartment immediately below the shell chamber, and are controlled from the sighting stations.

The handles G for hand working are situated in the same compartment as the hydraulic engines, and are suitably connected by gearing to the training shafts *f*. An automatic brake *d* is provided which will always be in action when the hand or hydraulic power is not actually at work, and the locking bolt *z* is arranged to secure the turntable when not in use.

The guns are mounted in cradles W, which slide during recoil upon slide frames I_1 built up of steel plates and angles. The slide frames are supported by trunnions *g* in bearings on suitable brackets attached to the upper part of the turntable.

The recoil presses H are fixed to the slide frames, two to each gun. These presses are provided with pistons and rods, the latter being attached to the cradle. During recoil, the liquid in the press is forced through an opening of varying area to give an approximate constant pressure throughout the period of recoil. The gun may be run out or in either by hydraulic or hand power. For running out or in by hydraulic power two presses are provided, one for each operation. These are fixed inside the slide frame under the gun and have a single ram working between them, which is secured to a sleeve on the under side of the gun cradle, and moves with it. The operating valves are situated on the gun platform.

For hand power run "out" and "in" hand pumps J are provided in the chamber below the turntable, and are suitably connected up to the "Run in and out Cylinders." These pumps are also used for hand "elevating," connections being likewise provided to the elevating presses LL.

For elevating by hydraulic power, a bracket K attached to the underside of the slide frame in front is connected by means of two links *k* to the ram of a press LL which is attached to the floor of the turntable. This press is operated either from the sighting platform or the gun platform. The hydraulic supply is conveyed to the revolving turntable by means of the swivel pipes PP.

Automatic sighting gear is provided on the gun mounting, and is arranged in duplicate for each gun.

The projectiles and explosive charges are conveyed from the shell rooms and magazine to the shell chamber in cages which travel along guides in the trunk. The projectiles are transferred from the overhead traveller *y* in the shell room on to two bogies Y at the base of the trunk. These bogies are provided with gear for running them round relative to the ship or to the revolving trunk, and have bolts which support the projectile, which, when withdrawn, allow the projectiles to roll down on to a receiving tray in the cage. The cages in the trunk travel vertically until they reach the chamber below the turntable, whereupon the trays carrying the projectiles are automatically tilted so that the projectiles roll on to receiving trays n_1. These trays are themselves tilted on a horizontal axis until they come in line with the inclined trays n_2 leading to the ammunition cages, which carry the ammunition from the shell chamber to the gun breeches.

The rails SS, leading from the shell chamber to the gun platform have their upper parts curved concentric with the trunnions so that the projectile carried on the cage is always radial in the upper part of its course and may be brought in line with the bore of the gun whatever be its elevation.

The powder charges are raised from the magazine, which is situated immediately above the shell room, to the shell chamber in cages Q, which travel up guides in the trunk in a similar manner to the shell cages. The charges are then lifted out and placed in the main ammunition-hoists R_1 leading to the gun breeches.

A loading tray T, arranged to work on a horizontal axis, is kept by a spring in its lower position out of the way of the gun when it recoils. This tray is raised by a cam on the ammunition cage and swung around its horizontal axis into the bore of the gun after the breech has been opened, and in this position effectively protects the threads of the breech screw during the passage of the projectile and powder charges into the gun. At the rear of this loading tray a chain rammer V is provided, worked by means of a hydraulic motor, the arrangement being that the rammer is always in line with the longitudinal axis of the gun, for loading at any angle of elevation.

The motor for working the rammer is attached to the arm I_2 which carries the loading tray and connected by bevel gear v to the rammer.

Should the motor or other part of the gear fail, a clear space may be provided for hand loading from a bogie R_2 at the rear of the gun by lowering the gearing and its connections by means of a screw.

All the ammunition cages are worked by hydraulic cranes. The main ammunition cages abut against fixed stops on the rearward extension of the slide frame, so that the projectile is brought exactly in line with the bore of the gun, thus ensuring that the gun may be loaded at any angle of elevation, whether in motion or at rest.

The mounting is enclosed by a shield M securely attached to the upper floor of the turntable by suitable plates and angles. The front and sides are sloping. The rear part is extended to provide space for the gun's crew, and also serves to balance the mounting. The opening between the shield and the barbette wall is made water-tight by means of a flexible leather apron *m*, which may be adjusted by means of screws.

There are two sighting hoods and one look-out hood at the rear.

Vickers Foreign Service Mounting for Two 12-*Inch B. L. Guns.*—The diagram, Fig. 22, Plate 75, differs in one important respect from the arrangement for the British ships just described. Each charge for the main hoist is transferred direct to the gun hoist, the elevator trunk being splayed outwards at the top so that the projectiles are brought up exactly in line with the axis of each gun. In this arrangement nine projectiles are always kept in motion in various positions, and the guns are constantly kept supplied with ammunition so that they may be virtually considered quick firers. It is only necessary to describe in detail that part of the ammunition hoist which differs from the arrangement in the mounting, Plate 74.

The cages N in the conical trunk travel upwards on slightly inclined rails *m* until they reach the chamber below the turntable, and the projectiles which they carry are now in line with the guns. The cages are provided with trays carrying the projectiles which are automatically tilted when the cage has ascended, so that the projectiles slide off into fixed receiving trays *p* in the shell chamber, where they remain until the ammunition cages R, which carry the ammunition from the shell chamber to the gun breeches, have descended and automatically set free the stops which retained them in position, permitting the projectiles to slide into the ammunition cages.

9·2-*in. Gun Barbette Mounting.*—On Fig. 23, Plate 76, there is illustrated the equipment for a medium calibre gun specially suited for armoured cruisers, which, for its size, has attained the greatest rate of fire of any gun at present mounted in H.M. Navy. This is a 9·2-inch equipment, which is to all practical purposes similar to the guns Messrs. Vickers, Sons and Maxim have now under manufacture, with their mountings, for the Turkish battleship "Messudijeh." A general description of the mounting is given, as it is of special construction, and is capable of attaining a rate of fire of five rounds per minute. The mounting itself would not produce this extraordinary rate of fire; it is due to the construction of the breech mechanism illustrated by Fig. 12, Plate 70, and described on page 515, in combination with the general arrangement of the mounting. The breech mechanism can be operated, either in opening or closing, in about two seconds, so that very little time is wasted in performing the whole operation. Neither hydraulic nor other mechanical device is needed, as the arrangement of levers gives ample power when worked by hand. The following is a detailed description of the mounting as illustrated by Fig. 23, Plate 76:—

The turntable A is built up of steel plates and angles. The upper roller path *a* is riveted to its under face and machined up true in position. The lower roller path *b* is secured to a machined surface on the floor of the barbette. The rollers BB are provided with flanges at both ends to take the horizontal thrust, and are bound together by a ring of plate steel to which the roller axles are attached.

The turntable is arranged to be rotated either by hydraulic or hand power, the former by means of a three cylinder hydraulic motor F, gearing with a rack E attached to the lower roller path, and the latter by means of handles D situated on the gun platform. The shaft carrying the pinion which gears with the training rack is arranged vertically, and carries two spur wheels f_1, f_2, loosely thereon, to one of which is geared a pinion on the shaft of the hydraulic motor, and to the other is geared a pinion connected to the hand gear. The wheels are connected to the shaft by means of a clutch f_3, so arranged that only one can be in operation at the same time.

A hand brake is provided for securing the turntable when changing from hydraulic to hand power, and *vice versâ*. The hydraulic motor is controlled from the sighting station by means of the hand wheel N.

The gun is mounted on a slide frame S built up of steel plates and angles, provided with bearings upon which the gun slides during recoil. The slide frame is supported by trunnions on bearings *g* in suitable brackets G secured to the upper parts of the turntable.

The recoil presses H, two in number, are fixed to the slide frame. These presses are provided with pistons and rods *h*, the latter being attached to the lug band C secured to the gun, and arranged to slide on a prolongation of the slide frame. The presses have an orifice of varying area to allow the liquid in the cylinder to pass from one end to the other during recoil at an approximately constant pressure.

The gun is provided with two rows of recuperator springs placed inside the slide frame, which hold the gun in the firing position, and are of sufficient power to return the gun after fire to the firing position at all angles of elevation. Suitable arrangements are made in the recoil cylinders to prevent the shock when returning to the firing position with the gun horizontal or depressed.

The gun is arranged to be elevated either by hand or hydraulic power. The elevating press P is secured to the turntable below the gun, and is connected by links *p* to the bracket R on the underside of the slide frame. The press is controlled by a lever *n* from the sighting station. Hand wheels are provided at the sighting station for elevating by hand I_1, and also from a secondary position in the gun platform I_2. They are connected by worm and other gearing to the elevating arcs K attached to the underside of the slide frame, two pinions *q* on the worm wheel shaft being geared thereto. An automatic arrangement is provided for disconnecting the hand gear when the hydraulic power is employed.

Automatic sights *ss* are provided on the gun mounting, and an indicator situated at the sighting station shows the position of the mounting relative to ship when training.

An arm Q attached to the gun-slide supports the loading tray L_2, on to which the projectiles are placed for loading. The mechanism of the loading apparatus is such that the projectile always remains parallel with the axis of the gun when the tray with shell is swung into the breech of the gun.

From the under floor of the turntable a trunk T_1 is arranged to extend down into the interior of the ship to the level of the ammunition chambers. It is rectangular in section, and the interior is used as a passage-way and hand-up. The guide rails *rr* for the ammunition hoists are fixed to the outside. A platform T_2 is attached to the underside of the turntable, and revolves with it, from which a ladder L_1 extends to the gun platform; it may be used for carrying the spare ammunition for handing up.

The projectiles are delivered on one side of the gun, and the powder charges at the other, one projectile and two half-charges being conveyed at a time. The shells slide down an inclined trough T_3 from the cage to a convenient position at the rear of the gun, from whence they are lifted into the loading tray. The powder charges are carried round by hand to the rear of the gun. Both hoists are worked by hydraulic presses.

The projectiles and powder charges in case of necessity can be raised by hand through the ladder ways to the gun platform.

The mounting is enclosed by a shield M, securely attached to the upper floor of the turntable by plates and angles. It is provided with a sighting hood, and is fitted with a leather apron *m* with screws and brackets for making it water-tight with the barbette.

Krupp Barbette Mounting for 24-*cm.* (9·45-*inch*) *Gun.*—In dealing with the mountings of heavy ordnance, it may not be amiss to refer to a type of 24-cm. gun designed by Messrs. Krupp, of Essen, of which a general diagram is given on Fig. 24, Plate 77. The main operations of this mounting are performed electrically, but the mechanism can be quickly disconnected to enable the gun to be worked by hand. The recoil of the gun is overcome by a hydro-pneumatic device, and the rammer is worked by hydraulic power. Messrs. Krupp thus fit three power systems for performing different operations in connection with the working of one mounting. The breech mechanism of the gun is of Messrs. Krupp's usual wedge type, and is worked by hand. It is claimed for the mounting that it will fire one round every twenty seconds; that is, starting with the gun loaded, four rounds in the first minute and then one round every twenty seconds thereafter. The turntable itself revolves on a ball race, and the mounting generally is well protected by the highest quality of armour. The maximum rate of fire obtained from the Vickers 9·2-inch mountings was five rounds in one minute, starting with the gun loaded; and, as already pointed out, this extraordinary rate of fire from such a heavy weapon has been accomplished by the combination of the general arrangement of the mounting with the mechanism of the gun and the abolition altogether of the metallic cartridge case. The following is a detailed description of the Krupp barbette mounting for 24-cm. breech-loading gun, as illustrated by Fig. 24, Plate 77:—

The mounting consists essentially of the following parts:—
The turntable A for loading the ammunition hoist;
The rotating trunk B carrying the gun platform C and carriage D;
Training and elevating gear E;
Ammunition hoisting gear F and rammer G;
Gun shield H.

The turntable, which is rotated by hand power on a live roller path, is built up of plates and angles, and carries twenty-four projectile holders K arranged in a circle, and secured by clips. The trunk, which rotates independently of the turntable, is centred at its lower end by a pivot L, which rotates in a fixed bearing. Rails attached to the trunk guide the cap M while it is being elevated. The upper part of the trunk is circular, and is strengthened by cross girders N and angles to carry the gun platform and carriage. A ball path fixed to the under side of the platform rests on a racer P fixed to the deck, and provided with steel balls, which thus support the trunk and gun mounting, while clips fitting underneath an internal flange on the racer prevent the ball path unseating when firing.

The traversing rack Q, which gears with the traversing pinion, is formed on the outside of the racer. Traversing may be effected either by electric or hand power, the crank handles R for the latter are placed in a pit immediately below the platform, and connected to the traversing shaft by a chain drive and double speed gear. Access to this pit is obtained through hatchways in the platform. When the maximum traverse has been reached in either direction, the platform comes in contact with a spring buffer, and the motor automatically thrown out of gear. A powerful electro-magnetic brake is also provided.

The elevating arcs attached to the cradle crosshead are provided with graduated sectors S, and gear with the elevating pinion, actuated either by an electric motor T or by hand power, and an indicator U actuated by the sight registers the angle of elevation required. The movement of the arcs is limited by stops, the motor being automatically thrown out of gear when maximum elevation or depression is reached, and an arrangement is provided for locking the gun at the elevation necessary for loading.

The controlling levers for the traversing and elevating motors are actuated from the sighting station, and the change from electric to hand power is accomplished in a few seconds by means of clutches.

The gun is mounted in a cast-steel cradle V, and the cradle supported in the carriage by trunnions, so that during recoil the gun slides in the cradle. The two recoil cylinders are formed on a crosshead, fixed to the cradle, and the running-out cylinder placed between them; each recoil cylinder is provided with a piston and rod, the latter attached to the horn on the gun. During recoil the liquid in these cylinders is forced through an opening of varying area, to give an approximately uniform pressure, throughout the period of recoil. Compressed air in the running-out cylinder being further compressed during recoil serves for running out the gun. The air cylinder is provided with regulating valve and manometer gauge.

A range finder and automatic sight are fitted to the mounting.

One projectile and one charge are elevated simultaneously from the turntable to ramming position, the inclination of the hoist tray W being controlled by the guide rails fixed on the trunk. The tray is pivoted in the hoist cage and has two divisions, the upper which is movable for the charge, and the lower which is fixed for the projectile. The charge is placed in a swing carrier and secured by a clip, which is automatically pushed back on bringing the carrier into position for loading the tray. The projectile in its holder is lifted up by means of a hook and lever into a position which allows it to be pushed into a carrier Y fixed on the trunk, where it is secured by a spring catch, which on withdrawal allows the projectile to be pushed into the lower division of the tray. The cage is elevated by a rope Z coiling on a drum actuated by the electric motor F. The motor is slowly started by hand, and the cage on rising automatically throws in the full current; on reaching the gun platform, the tray cuts out the current, and is then brought to rest in position for ramming the projectile by a stop, the cage being held in this position by an automatic clutch. At the lower part of the trunk an arrangement is provided which indicates the position of the tray in the hoist, together with a bell, speaking tube, and telegraph for communicating with the gun platform.

The rammer is arranged to be in line with the gun's axis, and consists of a series of telescopic rams actuated by compressed air or by hand. After the shell is rammed, a lever is withdrawn which allows the charge to fall into the position previously occupied by the projectile.

When the elevating tray is loaded, a slight rotation of the turntable brings another projectile opposite the carrier Y, in which the projectile may be placed in readiness for the descent of the tray, and at the same time an empty holder is brought opposite a loading table where it receives a projectile, and is replaced in position on the turntable by an overhead trolley and swing link X.

An arrangement of a trolley running on rails concentric with the trunk combined with a swing link J is provided for loading direct from the depots.

The mounting is enclosed in a shield securely attached to the gun platform by stretchers and angles, the front sloping and the rear extended over the barbette to provide space for ramming. The shield extends downwards to the top of the barbette wall, and is provided with a sighting hood and manhole at the rear.

The Super-imposed Turret-Mounting adopted in U.S. Battleships.—Reference should be made to the unique system of super-imposed turret-mounting as adopted by the United States Government for the battleships "Kearsage" and "Kentucky," as illustrated by Fig. 25, Plate 78. This system of mounting heavy guns has the great advantage of concentration of heavy gun fire right ahead or right astern, and for a considerable arc on the beams of the vessel. This utilisation of the heavy gun fire capacity of a ship through so great an arc cannot be lost sight of by the artillerist. The increase in weight of armour necessary for the protection of the four guns is proportionately much less than if the guns were placed in pairs or singly in turrets, and the saving thus effected may be utilised in other directions to add to the fighting efficiency of the ship. Another advantage of the super-imposed turret system is that all four guns can be fired from one sighting position, so that one gunner may suffice for their laying and for their simultaneous firing. The gun layer in the first instance lays one of the guns for the correct elevation, and the other weapons are then brought to the same inclination by the man in charge of each. The four weapons may then be fired either together or separately by the captain of the turret.

The disadvantages, however, of the super-imposed turret system may perhaps be said to outweigh the advantages, as any serious damage to the turret would render four guns useless. The weight of armour protection of the four guns concentrated at a great height involves a problem for the ship constructor. The area of the superimposed gun turret presents a large target for attack. If it became necessary to repair one of the heavy guns, it might become a somewhat difficult operation to remove it, although in the case of the "Kearsage" one of the 13-inch guns was very smartly withdrawn for repairs recently without removing the upper works. The firing of four guns simultaneously necessitates considerable constructional strength of the ship in order to stand the heavy strains. This cannot however be put down as a serious objection, as these strains have been efficiently met by good construction in the American ships.

The following is a detailed description of this barbette mounting for two 13-inch and two 8-inch breech-loading guns in superposed gun turrets as adopted in the U.S. Navy and illustrated by Fig. 25, Plate 78:—

The two 8-inch guns are superposed upon the housing of the 13-inch guns. The 8-inch turret M_1, being rigidly attached to the roof of the lower turret M_2, is moved in unison with the motion of the latter, so that all four guns must be brought to bear in the same direction. The guns with their housings are carried on a turntable A, arranged to revolve on a live roller ring B.

The turntable A is built up of steel plates and angles, and is specially constructed for the attachment of the heavy armour plates composing the lower gun house. The main girders and upper surface are provided with suitable facings for the attachment of the brackets which support the gun mountings.

The rollers B, which support the turntable, are provided with flanges at both ends to take the horizontal thrust. They are bound together by rings of plate steel, to which the roller axles are secured, the whole forming the live roller ring.

Electric power is provided for the horizontal training of the guns. The training shafts, of which there are two, are carried vertically in the turntable, and have pinions at their lower ends, gearing with the training rack, which is secured to the lower roller path structure.

The electric motors are situated inside the turntable, one at either side, and are connected by worm and other gearing to the training shafts. The driving worms are carried on a horizontal shaft supported inside the turntable, and arranged so that the end thrust of the worms is directly opposed the one to the other and thereby balanced. The wormwheels are connected to the training shafts by a system of friction gear, which prevents undue stress on the gearing when the guns are fired separately.

The two 13-inch guns are supported in cradles S_1, which are circular in section. The cradles are in two parts, an upper and lower, and are bolted together along the horizontal axis; bearing strips are provided in the cradles, along which the guns slide during recoil. The forward end of each cradle is provided with trunnions g, arranged to rest on brackets G_1, secured to the upper part of the turntable. The recoil and run-out spring-tubes H_1 H_1, of which there are four to each 13-inch gun, are on the hydraulic system in combination with heavy recuperator springs which run the gun out after firing; they are disposed in pairs, two being attached to the upper part of the cradle and two to the lower portion. Suitable brackets are provided on the cradles to receive the tubes.

The spring-rods are attached to lugs provided on a band D secured to the rear end of the gun.

The two 8-inch guns are mounted in cradles similar to the 13-inch guns. The cradles are supported by trunnions on brackets G_2 attached to the roof of the 13-inch gun-house. Two recoil and run-out spring tubes H_2 are provided for each gun, and are fixed to the underside of the cradles.

The guns are arranged to be elevated by hand and electric power. Separate elevating gear is provided for each gun. The brackets carrying the elevating mechanism for the 13-inch guns are secured to the main girders of the turntable below the guns. A crosshead, guided in the supporting bracket, is operated by means of a helical screw, and is connected by links to a bracket on the underside of the gun cradle. The screw is worked by the electro-motor Q attached to the lower end of the elevating bracket, and by handles provided on each gun platform. The elevating gear for the 8-inch guns is secured to the roof of the lower gun-house.

The projectiles and powder charges are conveyed directly from the ammunition chambers in the interior of the ship to the gun breeches by means of suitable hoists. Separate hoists are provided for each gun, the 8-inch hoists being loaded in the chamber immediately above the 13-inch ammunition chamber.

The ammunition cages are raised by electro-motors T_1, T_2, and are arranged to take up one projectile and the powder charges at each operation. They are guided on rails r_1, r_2 to the loading positions at the gun breeches. Transporting rails t_1, t_2 and runners and loading bogies are provided in the ammunition chambers for transferring the projectiles to the ammunition cages.

The guns are arranged to be loaded at a fixed loading position. The telescopic rammer, situated at the rear of the shield, is in line with the bore of of the gun at the loading angle. These rammers are operated by means of electro-motors, provision being also made for working by hand.

An American 13-*inch B.L. Gun, Barbette Mounting.*—Another type of American mounting, illustrated by Fig. 26, Plate 79, is now being installed for the 13-inch guns of the "Illinois" class. As is the case with the superposed turret system, the power utilised is electric. The special novelty consists in the means adopted for overcoming the energy of recoil, which is effected by four hydraulic cylinders containing also springs for running the gun out after recoil. This is one of the first types of mountings for such heavy guns as 13-inch weapons, where the ordinary recoil cylinder is utilised for taking up the energy of recoil in combination with the spring return. This recoil system is very simple in arrangement, and is not likely to get out of order. It, however, entails a very heavy cradle and a large number of springs. The springs contained in two cylinders are amply sufficient to run the gun out in a horizontal position, and thus several springs may break before the system entirely fails. The author, however, prefers the British system of taking up the energy of recoil with two separate cylinders and of running the gun in or out by the ordinary hydraulic ram. The United States Government have, however, adopted electricity for the general working of their mountings and do not consider it expedient to introduce in addition hydraulic power in connection with recoil and running out. Their arrangement of bringing the ammunition up to a fixed position, which they elect to be horizontal, is decidedly superior to the system under which the gun requires to be elevated to a high fixed angle, as is the case in many loading systems for heavy guns. By loading the guns in the horizontal plane it seldom becomes necessary under normal conditions to relay the gun after loading, if there is any motion at all to the ship. The system, however, cannot be regarded as equal to that adopted by the British Government of loading at all angles of elevation, which is suitable for the position in which the gun is at any time being fought. As the gun can thus be loaded at any position, the gun layer can always keep both his gun laid in elevation and direction, and fire it immediately the word is passed that the gun is loaded. When it is necessary with other systems to change the gun even to a small angle of inclination for loading, the gun layer, after it is charged, often experiences considerable difficulty in getting his sights "on," and sometimes, in rough weather, even in finding the target. This condition never arises when the gunner's eye is always along the sight and always looking at the target during the process of loading, as is possible with the British system.

The details of the Barbette mounting for two 13-inch breech-loading guns (U.S.A. type), may be described as illustrated by Fig. 26, Plate 79.

The two guns are mounted on a turntable A, carried on a live roller ring, and are protected by a heavily armoured shield M, which is built to the upper surface of the turntable.

The turntable A is built up of steel plates and angles, and is specially constructed for the attachment of the heavy armour plates. The main girders and upper surface of the turntable are provided with suitable facings for the attachment of the brackets G, which support the gun mounting. On the underside of the turntable a suitable seating is provided for the attachment of the upper roller path *a*, which is secured by bolts. The lower path *b* is fixed to a structure C, separate from and within the barbette walls.

The rollers B, which support the turntable, are provided with flanges at both ends to take the horizontal thrust. They are bound together by rings of plate steel, to which the roller axles are secured, the whole forming the live roller ring.

Electric power is provided for the horizontal training of the guns. The training shafts, of which there are two, are carried vertically in the turntable, and have pinions at their lower ends gearing with the training rack E, which is secured to the lower roller path structure. The electro-motors are situated inside the turntable, one at either side, and are connected by worm and other gearing to the training shafts. The driving worms are carried on a horizontal shaft supported inside the turntable, and arranged so that the end thrust of the worms is directly opposed the one to the other and thereby balanced. The worm wheels are connected to the training shafts by a system of friction gear, which prevents undue stress on the gearing when the guns are fired separately.

The guns are supported in cradles S, which are circular in section. The cradles are in two parts, an upper and a lower, and are bolted together along the horizontal axis, bearing-strips being provided in the cradles along which the guns slide during recoil. The forward end of each cradle is provided with trunnions *g*, arranged to rest on brackets G, secured to the upper part of the turntable.

The recoil and run-out spring tubes HH, of which there are four to each gun, are on the hydraulic system in combination with heavy recuperator springs which run the gun out after firing; they are disposed in pairs, two being attached to the upper part of the cradle and two to the lower portion. Suitable brackets *hh*, are provided on the cradles to receive the tubes. The spring rods F are attached to lugs provided on a band D, secured to the rear end of the gun.

The guns are arranged to be elevated by hand and electric power. Separate elevating gear is provided for each gun. The brackets K, carrying the elevating mechanism, are secured to the main girders of the turntable, below the guns. A crosshead L, guided in the supporting bracket, is operated by means of a helical screw N, and is connected by links P to a bracket on the underside of the gun cradle. The screw is worked by the electro-motor Q, attached to the lower end of the elevating bracket. The handles J for hand working are situated on the gun platform and are suitably connected by gearing to the elevating screw.

The projectiles and powder charges are conveyed directly from the ammunition chambers in the interior of the ship to the gun breeches by means of suitable hoists. Separate hoists are provided for each gun. The ammunition cages R are raised by electro-motors, and are arranged to take up one projectile and the powder charges at each operation. They are guided on rails *r r* to the loading position at the gun breeches. Transporting rails and runners and loading bogies are provided in the ammunition chambers for transferring the projectiles to the ammunition cages.

The guns are arranged to be loaded at a fixed loading position. The telescopic rammer W, situated at the rear of the shield, is in line with the bore of the gun at the loading angle. This rammer is operated by means of an electro-motor *w*, provision being also made for working by hand.

Twin Q.F. Guns in Barbette Mountings.—In the case of cruisers, where saving of weight is of great importance, it is desirable to mount in the fore and after barbettes quick-firing guns singly or in pairs. Where two are to be mounted on forecastle and poop, it is important to have them on separate mountings not too close together, as otherwise one gun may interfere with the other whilst loading. When thus in pairs the processes of elevation and training are carried out together, and the guns loaded simultaneously. But in view of the necessity of being able to attack at very long ranges the author would substitute for the two 6-inch guns in many cruisers a 7·5-inch weapon firing a projectile of double the weight of the 6-inch at more than double the energy.* From such a single gun a greater rate of fire would be obtained than is possible with the twin 6-inch guns, because the close proximity of the two guns must hinder operations greatly. The advantage gained by utilising the heavier projectile at long range would fully compensate for any advantages of the twin guns of lighter calibre.

Fig. 27, Plate 80, illustrates the 6-inch twin quick-firing gun barbette mounting, of which the following is a detailed description :—

The two guns are arranged close together in one cradle; they are mounted on a turntable carried on live rollers, and are protected by an armoured shield secured to the upper surface of the turntable.

The turntable A is built up of steel plates and angles well riveted together; on the upper face of the turntable suitable machined faces are provided for the attachment of the brackets G supporting the mounting. The upper roller path *a* of special forged steel is riveted to the under face of the turntable and machined up true in position. The lower roller path *b* is secured to a machined surface on the floor of the barbette.

Rollers B of special forged steel support the turntable; they are provided with flanges on both sides to take the horizontal thrust; they are bound together by a ring of plate steel to which the roller axles are secured, the whole forming a live roller ring.

The turntable is arranged to be rotated both by hand and electric gear. A vertical shaft C carries a pinion F at its lower end, gearing with the training rack E, attached to the lower roller path. On the same shaft, the necessary gear is provided for connection to the electro-motor and to the hand gear. Provision is also made so that only one form of power can be in operation at the same time.

The electro-motor N is of the armour-clad, water-tight, shunt-wound type; it is controlled from the sighting stations at each side of the mounting.

Handles P are provided for men at the rear of the turntable behind the guns; they are connected to a worm wheel on the vertical training shaft by means of suitable gearing.

The mounting consists of the forged steel cradles S, of semi-circular section, with bronze bearing strips at front and rear, securely bolted together.

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* Since this was written it has been announced that the Admiralty have decided to make this change in the six new cruisers of the "Monmouth" class to be built shortly.

Forged steel caps R are fitted over the front parts of the cradle to retain the guns and to facilitate removal. The cradles are provided with trunnions *g* arranged to rest on brackets G built up of steel plates and angles and steel forgings.

The elevating arc is placed below the guns, the upper end being attached to the rear part of the mounting, while the lower end is connected by forged steel links to the front of the cradles between the guns. A pinion on a transverse shaft below the guns is provided for actuating the guns. The outer end of the shaft is furnished with a worm wheel attached to the shaft by means of friction plates. The worm which gears with the wheel is arranged to be worked by two hand wheels *p* at the sighting stations, one on either side of the mounting, and from a secondary hand wheel *q*. Independent recoil cylinders and run-out springs are fitted for each gun.

The recoil cylinders H are of cast manganese bronze, and are rigidly attached to the underside of the gun cradles. They are constructed to unite in the centre between the guns, and are bound together with securing bolts at the junction.

The piston-rods are of forged steel attached to the lug on the gun; an orifice in the piston provides for the passage of liquid from one side of the piston to the other when the gun recoils after fire.

Two recuperator springs K are provided for each gun, placed one on each side of the recoil cylinder; they are of sufficient power to ensure the gun running out at all angles of fire even with a considerable heel of ship.

Two sighting stations are provided, one on each side of the mounting, with hand wheels arranged so that the guns can be operated from either side. The sights *s s* are supported by a rigid structure W from the floor of the turntable, independent of the mounting. An arm *w*, fixed to the gun cradle and moving therewith, operates the rear sight bar on each side.

To provide for the rapid supply of projectiles, a carrier D is arranged inside the barbette, outside the turntable, and connected thereto by means of suitable gearing. This gearing is arranged to rotate the carrier ring bringing the projectiles underneath the openings provided in the gun platform, so that they can be readily transferred to the breech of the gun for loading. The carrier ring shown on the drawing is arranged to carry 153 projectiles.

Provision is made for a constant supply of powder charges from the magazines to the gun platform. A chain hoist Y, with suitable receptacles *v*, is arranged to take up the powder charges in a horizontal position. The chains are arranged to pass over sprocket wheels at the top and bottom of the revolving trunk T attached to and revolving with the turntable. The charges are delivered at each side of the gun mounting. On one side they pass over the sprocket wheels, and are received in an inclined tray. An auxiliary chain and tray, driven at a greater velocity than the hoist lifts every alternate charge, and delivers it on the opposite side of the gun mounting. If necessary, projectiles could be arranged to be carried in every alternate receptacle, so that the latter might be delivered on one side of the mounting and powder charges on the other side. The hoist is actuated by means of an electro-motor situated at the base of the revolving trunk with all necessary attachments and gearing.

The mounting is enclosed by an armoured shield M, securely attached to the upper floor of the turntable by a suitable steel angle-bar frame. The shield is fitted with a leather apron *m* with suitable screws and brackets for making it water-tight with the barbette. Two sighting hoods are provided.

Centre Pivot Mounting.—Reference may next be made to the centre pivot mounting, largely adopted for quick-firing guns, and of which a typical example, constructed by Messrs. Vickers, Sons and Maxim for the Japanese Government, is illustrated by Figs. 28 and 29, Plate 81, while on Plates 82 to 87, there are reproduced photos taken of several guns during firing trials at the Vickers ranges at Eskmeals. Figs. 30 to 32 show the 6-inch gun on the centre pivot mounting, Figs. 33 and 34 afford a comparison between the 6-inch and 7·5-inch guns, the latter having double the power of the former, while Figs. 35 to 37 show one 9·2-inch gun.

The 6-inch quick-firing gun pedestal mounting, illustrated in detail on Figs. 28 and 29, Plate 81, is typical, and may be described.

The mounting consists of a steel top carriage A, which rests on a horizontal ball-bearing on top of a hollow steel pivot B, on which it may be revolved. The gun is free to slide during recoil in a cylindrical cradle C, which is balanced on its trunnions in suitable bearings in the carriage. Underneath the cradle are attached three cylinders, one, D to overcome the recoil, and the other two, E and F (one on each side of the recoil cylinder) containing the springs for running the gun up to the firing position after the recoil. The connection between these three cylinders and the gun is made by arms G and H projecting from the breech ring of the gun. The whole weight of the revolving parts, gun-cradle and carriage, is balanced on the ball-bearing, thus the training is very easy. The elevating and training operations are performed by the rotation of two hand-wheels, J and K, conveniently arranged with regard to a shoulder piece L, against which the gunner may lean.

These two hand-wheels, J and K, are situated on the left-hand side of the mounting, but an auxiliary training hand-wheel M, is provided on the right-hand side, so that two men may be employed to train the gun if desired. The training gear is so arranged that it may be easily and quickly thrown in or out of action.

The recoil cylinder D is of usual construction to give an approximately uniform pressure during recoil, and to control the speed of running out of the gun after recoil.

Provision is made for readily mounting and dismounting the gun, and to allow for this the trunnion bearings, N and N, are made in the form of circular caps, being so arranged that a partial rotation of the caps frees the trunnion of the cradle, so that the gun and cradle together may be drawn directly to the rear without any lifting being necessary.

The shield O is of the usual Casemate type.

An electric contact P is fixed on the cradle, and is so arranged that unless the gun is fully run out to the firing position it is impossible to fire the gun electrically.

Sights Q Q are provided on both sides of the mounting.

GUNS TO REPEL TORPEDO AND SUBMARINE BOAT ATTACK.

The 14-*Pounder Semi-Automatic Gun.*—Of the type of naval ordnance specially used for repelling submarine and torpedo attacks, including weapons firing 3-pounder, 6-pounder, 12-pounder, or 14-pounder shot, the 14-pounder now adopted by the United States Government is a typical example. Torpedo or submarine boats attacking ships or fleets at anchor would do so at very long range, and would probably commence to fire their torpedoes from a range of nearly 2,000 yards. The guns for repelling such attack would have to be of power sufficient to stop the boats before they came within striking distance of their quarry. The United States Navy have therefore done the right thing in utilising a shell of at least 14 lbs. weight. Such a shell is certainly superior for dealing with high ballistics at long ranges, and is about the weight generally adopted as a minimum by most countries for their land service artillery.

This 3-inch (14-pounder) semi-automatic quick-firing gun is illustrated by Figs. 38 and 39, Plate 88; the semi-automatic breech mechanism is shown on Figs. 40 to 42, Plate 89, while a perspective view is given on Fig. 44, Plate 90.

The mounting consists of a pivot A, which works in a steel cone, or naval stand B, and has its upper part formed into a crosshead C. The cone is provided with gun-metal liners, and the pivot is secured to it by means of a pivot nut D. The cylindrical cradle E, in which the gun is free to slide in recoiling, is supported by trunnions F, in bearings formed in the crosshead; and it is provided with two hydraulic buffers G, in which work pistons attached to a lug on the underside of the breech end of the gun. The elevating and training are effected by means of a shoulder-piece H, attached to the cradle. The crosshead is fitted with a clamping screw, and a traversing clamping segment which fits into a groove K in the liner. When tightened by means of the handle L this segment secures the gun in any required position of training. A similar handle at M clamps the gun at the desired degree of elevation. Protection is afforded the gunner by a shield N, which is bolted to flanges P, forged on the crosshead jaws. The cylinders of the hydraulic buffers are provided with tapered grooves, which allow the oil to escape round the piston heads, and so regulate the flow that a constant pressure is maintained during recoil. Inside the cylinders are strong spiral springs surrounding the piston-rods, which, being compressed by the rear motion of the piston heads, cause the gun after firing to return to its former position.

The breech mechanism for 3-inch (14-pounder) semi-automatic quick-firing gun is shown on Figs. 40 to 42, Plate 89, and may be described in detail.

The gun rests in a cradle provided with two combined hydraulic and spring buffers, the piston-rods of which are connected to a projection at the breech end of the gun. In the rear of the cradle A is a pistol grip B, which contains the trigger C, and on the right-hand side is a detachable lever D, by the movement of which the breech block E can be lowered or raised. The breech block is capable of vertical movement, and contains the main spring F, firing-pin G, sear H, and cocking lever I. Situated between the buffers, underneath the cradle, is a powerful flat spring K, the action of which works the breech mechanism.

To prepare the gun for firing, the breech is opened by the movement of the hand-lever D, the handle of which is made to rest in a crutch prepared for its reception. By the movement of the hand-lever a crank M is turned, the action of which brings down the breech block E, and compresses the powerful flat spring K, situated between the buffers. At the same time the main spring F is compressed, and is kept in this condition by the action of the sear H. The breech block E in moving down strikes the lower extension O of the extractor, and causes the upper portion to move out from the face of the end of the barrel and brings two small projections P over the upper edge L of the breech block E, thus preventing it from rising by the re-action of the spring K. The cartridge is smartly pushed into the bore, and as it goes forward into the chamber its rim strikes against the extractor and forces back the projections P, which prevented the breech block from rising. The flat spring before referred to acts and rotates the crank M, thus raising the breech block until the breech is closed. The tail end R of the sear is now engaged with the toe S of the trigger, and by pulling the trigger pull C to the rear the trigger releases the sear, and the firing pin G is thrown forward by the action of the main spring F. On the pulling of the trigger the gun is fired and recoils in the cradle; the recoil, which is controlled by the hydraulic buffers, compresses the powerful springs round the piston-rods, and the re-action of these springs at once returns the gun into its original position in the cradle. As the gun returns, the action pawl T engages the hook U, on the crank M, which causes the crank to rotate and thereby to bring down the breech block. The extractor is actuated upon by the fall of the block; it first loosens the cartridge by a slow movement, which, rapidly increasing, finally ejects it to the rear.

The 3-Pounder Automatic Gun.—Another type of gun for resisting torpedo boat attack, namely, the 3-pounder, is one which at the present moment calls for much study. The gun selected for general description is one now being extensively used in the United States Navy, although the automatic device is at the present time only under experimental trial. The naval mounting for this 47 mm. (3-pounder) automatic quick-firing gun is illustrated by Fig. 43, Plate 90, and by Figs. 45 and 46, Plate 91, and the following is a detailed description :—

This mounting consists of the crosshead A, formed in one piece with a pivot turning in the socket B, which is supported by a cylindrical base C, and is secured thereto by a holding down ring D.

The cradle E, through which the gun recoils, is provided with a hydraulic buffer F, in which works a piston attached to a lug on the breech end of the gun. On the cradle are forged the trunnions G, which are supported in bearings H, formed in the jaws of the crosshead.

The elevating and training of the gun are performed by means of the shoulderpiece K, which is attached to the cradle.

Attached to the crosshead is the elevating segment N, grooved to receive the clamping bar P, which is attached to the cradle. This bar being tightened in the groove by means of the wheel R, the gun is fixed at the required elevation. A clamping screw is also provided in the socket B, which holds the pivot at any point of training.

A pair of arms LL, forming extensions of the crosshead, carry the shield M, which protects the man working the gun.

The cylinder of the hydraulic buffer is provided with grooves, which allow the oil to escape round the piston head, and so regulate the flow that a constant pressure is maintained during recoil. Inside the cylinder is a strong spiral spring surrounding the rod, which, being compressed by the recoil, causes the gun to return to its former position.

The hopper feed mechanism of this 47 mm. gun is of great interest. It is shown in detail in Figs. 47 and 48, Plate 91, and is thus described :—

Directly the gun recoils, it brings the carrier rest A under the lug B on the carrier C, and does not leave it until the gun has returned to its firing position; the carrier C can therefore under no condition descend until the gun is home. During the recoil, the face of the barrel breech forces the plunger D with its pawl and feeder E back, until the hook F on the pawl G passes the lug H on the shoulderpiece I. The pawl is raised by its spring K, and the hook F engages, with the lug H, thereby cocking the plunger piston D.

The gun returns, and at a certain distance from home the action pawl coming into play, opens the breech, and the ejection of the empty case begins.

When fully home, the carrier C descends, being clear of the carrier support A, and after being moved a certain distance it engages with the part of the pawl forming the feeder E, depressing it and finally disengaging the hook F from the lug H on the shoulderpiece I.

The plunger piston spring K re-acts and returns the plunger D, with its pawl and feeder E, to its original position, the feeder forcing the cartridge in the carrier forward, shooting it into the chamber.

The breech block L, during its ascent, raises the lifting lever M, and through it the carrier C. When this latter is nearly home, it engages through the projection with the tail N of the escapement, and moves it out of the path of the cartridge in the hopper O. The cartridge being thus liberated slides through the hopper into the carrier, its place in the hopper being taken by the next cartridge, which in turn is locked by the escapement as the carrier descends, and is liberated on the return of the carrier.

To load the gun the following operations are necessary:—Open the breech by depressing the hand-lever P, and return it to its original position. Insert a loaded cartridge in the breech beneath the carrier, and send it home in the chamber by a quick forward push, as in loading an ordinary semi-automatic gun. The breech will then close automatically. Charge the hopper and the gun is ready for firing.

The "Pom-Pom."—Guns to resist torpedo or submarine boat attack must also include the "Pom-Pom," now almost universally adopted as a high power automatic fire-arm specially applicable as a personal deterrent, when searching out for gun crews or others doing important duty on board torpedo vessels, or any war-ship, and not protected by armour. The rate of fire of the gun is about 250 rounds per minute, and each shell, weighing about $1\frac{1}{4}$ lbs., bursts on impact into about thirteen pieces. Such a gun, it will be recognised, is specially suitable for attacking gun crews in the fighting tops, etc., the hail of shell rendering it impossible for the men to remain exposed at their guns. When the German ships were recently attacking the Chinese Ports at Taku, the "Pom-Pom" drove the gunners away from the fort weapons, leaving them to be put out of action by the heavier calibre quick-firers on board the ship. Our Admiralty would therefore be well advised to have a few of these "Pom-Poms" on board every ship for such special duty, particularly as they can be utilised on landing carriages, in addition to sea-service or attack on coast defences. The experience during the Transvaal War has specially demonstrated their value as naval landing guns. Fig. 51, Plate 93, illustrates the "Pom-Pom" on a naval cone mounting. The general arrangement of its mechanism is similar to the rifle calibre Maxim gun, a photograph of which is reproduced on Figs. 49 and 50, Plate 92.

PROJECTILES AND PROPELLING POWDERS.

The question of projectiles for modern naval artillery is receiving the greatest attention in all countries. Nearly ten years ago the Russian Government commenced experiments with capped projectiles and demonstrated their advantage; recent developments in this country have led to their being ordered for use with guns of 12-centimètre calibre and upwards. For many years the French have utilised caps in connection with armour-piercing shell, and the United States have generally adopted a cap of the Johnson system for armour-piercing and semi-armour-piercing projectiles. Recent developments in Germany show that they are also about to use capped projectiles, and Messrs. Krupp, of Essen, are recommending one of their own construction, which greatly improves the armour-piercing power of the shell. The author, from experience, greatly favours the application of a cap to all armour-piercing projectiles for use against modern armour, although the advantages of the capped projectile against comparatively soft armour are not realised to any serious extent.

The types of armour-piercing shell are so numerous that no attempt can here be made to enter into details, but the author believes so much in the importance of the really armour-piercing shell from a naval point of view—the penetration of a ship's side when the projectile hits being so supremely important—that no money should be spared to secure the very best obtainable. Really regular and reliable results are only to be ensured by the best forged steel, and not from shells made from castings unforged.

The experiments carried out against H.M.S. "Belleisle" prove the destructive effect of the high explosive shells, if they penetrate through the armour or otherwise get into the interior of the ship, as described in this year's Brassey's Annual. The value of such shell against superstructures and the non-protected upper works of the ship is very great, but the attack of such parts of a ship would not be in any way decisive; the best way to put a ship really out of action is to perforate the armour near the waterline, or to get a large number of projectiles behind the armoured protection. Such results are only possible by perforating the modern hard-faced armour, and it would therefore seem supremely important in all armour-piercing shells which are now being utilised, that they should be made of such material as to ensure their being able to perforate the most modern hard-faced armour without breaking up, as is at the present time more usual. This the author believes to be only possible by using armour-piercing projectiles fitted with caps; he exhibited a 6-inch shell which a few weeks ago passed without injury through the latest type of 6-inch hardened plate with the very moderate velocity of 1,950 feet. A projectile so constructed and fitted with a cap would be able not only to pass through a 6-inch plate, but through a 12-inch plate should the necessary energy be given to the projectile, and the author has already indicated how such increased energy may be attained, even in our existing naval artillery. A semi-armour-piercing shell properly constructed and fitted with a cap would also have much greater powers of penetration than the existing semi-armour-piercing shell without a cap, and it would appear desirable that the largest portion of the projectiles carried on board all ships should be constructed of sufficient strength and fitted with caps so as to be capable of perforating modern armour, such as will be found on the ships of all our possible opponents. As from 70,000 to 80,000 tons of this armour is made annually for the navies of the world, at a cost of from 9 to 10 millions sterling, it becomes of very great importance that every effort should be made in constructing our shell to ensure the advantage in favour of the artillerist that has just been indicated. Only in this way can the gunner succeed against the armour-plate maker.

Next in importance to the armour-piercing or semi-armour-piercing shell come the large-capacity shells carrying a high explosive. For this purpose Germany and France, like Britain, make use of picric acid, but the Russian Government are utilising guncotton in shells up to 11-inch calibre.

In regard to propelling powders for guns there is not much difference of opinion, except in Great Britain, as to the most suitable compound; most countries have adopted or are about to adopt a nitro-cellulose powder. For use with rifles, England, Italy, and Norway may be said to be the only countries now using a nitro-glycerine composition of powder, whereas Germany, Austria, France, Russia, the United States, Spain, Denmark, Roumania, and the Spanish American States utilise entirely a nitro-cellulose compound. In regard to the explosives used for heavier artillery, Great Britain, Italy, and Austria are the only countries which have permanently retained the nitro-glycerine form, whereas Germany, France, Russia, the United States, Spain, and Japan utilise nitro-cellulose powder.

The most important considerations in determining the best composition of powder to be adopted are firstly, its keeping qualities and safety under normal climatic conditions; secondly, its capability of obtaining the highest possible ballistics and consequently the flattest trajectory; and thirdly, its regularity in results, so that the ballistics may not be seriously affected by change of temperature or by the wearing away of the gun due to excessive erosion. All these qualities are secured by the use of a properly manufactured nitro-cellulose powder, whereas none of these conditions can be said to be met by any powder containing nitro-glycerine.

At the present time the Russian Government manufacture the largest quantity of nitro-cellulose powder. Up to about two years ago all the conditions enumerated were not fulfilled, owing to the nitro-cellulose used for the powder not being quite satisfactory; but since then they have obtained the best results by using the system employed by the Cologne Rotweil Company at their factory at Schluselburg. In France and Russia also great difficulty was experienced at the outset in obtaining a really suitable nitro-cellulose, and in carrying out the necessary operations to render the powder really homogeneous and safe. Indeed it is only by careful study and much experiment that the manufacture of nitro-cellulose powder has now become really reliable and stable. The most serious experimental work in connection with this matter has been carried out by the Cologne Rotweil Company, at whose establishment extensive chemical research is always in progress. The Russian Government realised this some years ago, and in consequence gave this company a large number of orders, rendering it possible for them to establish large works in Russia for the development and manufacture of this highly important artillery necessity. Thus the average production in Russia of nitro-cellulose powder, manufactured upon a Rotweil system, amounts now to about 400 tons per annum.

It may not have been quite appropriate to introduce the subject of powder into a Paper on the mechanical engineering details of ordnance, but the reference made is probably justified by the important results following from the use of propelling powder of the nitro-cellulose composition. Indeed, it is, in the author's opinion, the only suitable compound for use with high power artillery: and as experiments have convinced the author that powders containing even a small proportion of nitro-glycerine are unsuited to guns developing high velocity, he believes that the British authorities would be well advised in adopting the nitro-cellulose compound. Difficulties, no doubt, would attend such change at the outset; but the wear of the guns at present, with all attendant disadvantages, makes the alteration almost imperative, especially when great power and rapidity of fire are sought for, as erosion increases at a much higher percentage with nitro-glycerine, and necessitates an exceptionally large reserve of guns being kept. So long, however, as we have in position of influence men of such perspicacity and judgment, actuated by the true progressive spirit, as Sir Henry Brackenbury, with such eminently practical and experienced advisory engineers as Sir Benjamin Baker, there is no reason for any despondency or any lack of faith in the future. This view is at the same time quite compatible with an earnest advocacy of the reforms dictated by personal experience ; that is but the duty of the citizen.

THE VELOCITIES ATTAINED BY MODERN GUNS.

And this raises the question of the velocities and ballistics generally of guns, and on Plates 94 and 95 are three diagrams: Fig. 52 shows the velocity, energies, and range of various types of 6-inch guns, Fig. 53 gives a comparison of the dangerous space of the 6-inch service guns, and of the Vickers weapon of the same calibre, and Fig. 54 a similar comparison for 12-inch breech-loaders. The diagram of the 12-inch gun, Fig. 54, shows well the value of increased velocity, the dangerous space of an object 30 feet high at a fighting range of 2,500 yards being increased by 162 yards in 523 yards when the muzzle velocity is accelerated from 2,500 to 2,700 feet per second. The former velocity is obtained with cordite (a nitro-glycerine compound) and the latter with nitro-cellulose powder. In the diagram of 6-inch guns the velocity of a gun firing at 3,000 f.s. is compared with the British gun now in most of our war-ships rather than with the latest type which is now being put into all the new ships. In this case the dangerous space at 2,500 yards distance from the gun is increased from 226 yards to 465 yards for a target 30 feet high, which would represent the freeboard of a warship or merchantman. These special cases establish the importance of high velocity in modern naval artillery, for at sea it is quite impossible to judge distances accurately at once, and errors in range need not involve the missing of the ship if the guns are of the highest possible energy, which means low trajectory and consequently an extended danger zone.

As to the diagram showing the curves of comparative energies of various types of 6-inch guns, Fig. 52, it indicates that if the British gun makes use of a nitro-cellulose powder giving a velocity of about 2,800 f.s., it will be well ahead in energy of the 6·4-inch French gun, to which it corresponds. The 6-inch gun installed in the majority of our ships, however, is not nearly so powerful as this particular weapon, as evidenced by the diagram. This great discrepancy in power could be eliminated even with these old-fashioned guns by slightly enlarging the chamber and by utilising a nitro-cellulose powder instead of cordite. This simple modification would result in the main armament of the majority of our battleships and cruisers being greatly improved.

Submarine Boats.

Submarine boats bear on the subject of Naval Ordnance—not so much in association with gunnery, but with torpedo armaments, which constitute a most serious factor in connection with our future naval history. Up to the present time the torpedo has been carried by most of our ships of war, but the maximum serviceability of the weapon must be obtained from such specially designed ships as the torpedo boat or torpedo boat destroyer. Now, however, a new field for the torpedo is opened out by the introduction of submarine or semi-submerged boats. Torpedoes are inoperative at a greater range than 2,000 yards, and must be discharged within closer distance, so that in the case of two vessels even otherwise unequal but armed with torpedoes, the chances of success would be equal, and thus it would be impolitic under most circumstances for the superior vessel to take the risk of being torpedoed. For this and other reasons mechanical torpedoes should be utilised by specially constructed vessels, and particularly by boats capable of remaining unseen except for momentary re-appearances to take observation. This is a condition fulfilled by a submarine boat much more efficiently than by torpedo boats of the ordinary type. Attack by daylight would make the latter almost certain victims of any ship armed with a moderately heavy quick-firing gun, escape being impossible; whereas the submarine boat, if discovered when porpoise-like she comes to the surface, can immediately dive, cruise under water for a few miles and make her escape to fight another day.

At the present time the French have thirty-four boats in various states of manufacture, twenty-nine of which are electric submarines and five submersibles, and they are now carrying out important trials and spending large sums of money in their development. Before many years have passed France will have not thirty-four but hundreds, with which she would be able not only to protect her ports, but to make attacks on her enemy's fleet in much the same way as the bands of Boers are making guerilla attacks on our regular army in the Transvaal. Of the continuous stream of ships passing up and down the English Channel—the busiest steamship track on the globe—quite 90 per cent. are British vessels, and upon them our mercantile greatness depends. Let us suppose that in time of war 100 French submarines were let loose in the Channel at night. These boats have sufficient speed and radius of action to place themselves in the trade routes before the darkness gives place to day and they would be capable of doing almost incalculable destruction against unsuspecting and defenceless victims. The same applies to the Mediterranean and other ocean highways within the danger zone of the submarine.

The submarine boat has thus increased the value of the mechanical torpedo tenfold. To the United States of America submarine craft will be of inestimable benefit, as it will render the coast practically secure against attack from any country excepting those having naval bases within easy striking distance of their littoral. The boat now universally adopted by the United States is built on the Holland system, and the new British boats building by Vickers, Sons and Maxim, at Barrow-in-Furness, are of similar design. They are to be almost equal in speed to the French boats, but have other qualities not attained by these boats, the principle of which is that they will be capable of behaving much in the same way as the porpoise. They are capable of coming up and disappearing instantly, so that they can thus determine exactly the mark to be aimed at before discharging the torpedo. The quality of being able to dive in a few seconds renders them much less vulnerable to attack by artillery.

The dimensions of the submarine boats which are being constructed for the British Navy are: length over all 63 feet 4 inches, beam 11 feet 9 inches, with a displacement when submerged of 120 tons. One torpedo expulsion tube is formed at the extreme forward end of the boat, and four of the 18-inch Whitehead torpedoes are carried, the gear being arranged so that the torpedo may be discharged with the boat stationary or running at any speed, and when the vessel is awash or submerged. The scantlings of the hull have been designed to withstand the pressures consequent on submergence at a depth of 100 feet from the surface, the double bottom tanks being utilised for ballast and storing purposes. Ingress and egress are through a conning tower of armoured steel 4 inches thick and 32 inches in external diameter, fitted with observation ports. The propulsion of the vessel awash is by a gasolene engine with four single-acting cylinders water-jacketed, actuating pistons of the trunk type, with long surfaces, the connecting-rods being attached direct to the pistons. The inlet and exhaust valves are of the poppet type, and are in the cylinder heads, the levers by which they are operated being actuated by hand, mounted by sleeves keyed to the cam-shaft running alongside and near to the top of the cylinder. The cam-shaft makes one revolution for every two of the main crank shaft, and the motion is transmitted by two pairs of skew gears through a vertical shaft. The electric ignitors are actuated by eccentrics also from the cam-shaft; the movable and fixed electrodes are fitted with platinum points. There being four cylinders it follows that there is an impulse for each revolution, and the speed may be varied from 200 to 360 revolutions per minute, giving a maximum power of 190 B.H.P. The boat has one propeller with blades, and the speed awash is expected to be 8 knots. Fuel is to be carried for a radius of 400 miles at this speed.

Propulsion when submerged is by an electric motor, which, like the gasolene engine, drives the shaft from the propeller through gearing with clutch connection. This gearing enables both gasolene engine and motor to be at a lower level than the shaft, which is on the centre line of the boat. For diving the boats are fitted with horizontal as well as vertical rudders, while at the same time a simple system of automatically arranging the disposition of water ballast is fitted to overcome any lack of horizontal stability consequent upon the diving action. Automatic means are also provided for determining the angle of diving or of rising to the surface, and to obviate submergence to excessive depths. At the same time hand gear for most purposes is fitted.

As to the periscope, of which the French speak so much, there is no doubt that when cruising submerged in the proximity of the enemy it will be very useful. It is an arrangement whereby a view of the surface through from 30 to 50 degrees can be obtained, and enables the boat when submerged to be steered directly for a visible point. The Holland boat has a special arrangement for effecting this purpose while enabling her to run at a distance below the surface so that no visible trace of her can be seen. Such an arrangement places this country quite on a level with the French nation, notwithstanding the fact that we may not in recent years have given the same amount of attention to submarine warfare.

To some extent the Marconi system of telegraphy affects the range of utility of the submarine, as the operation of blockading no longer entails the use of so many vessels because the distance through which a message can be signalled at sea has so much increased that one of our ships off the French coast may communicate direct with its base in Britain. It is true the speed of the submarine boat is not great, but progress is certain. When the Whitehead torpedo was first introduced it had a low speed, and generally speaking was very uncertain as to its direction, depth, and applied utility. Now however it is capable of running within a few inches of the required depth at a speed of over 37 miles an hour for a range up to 2000 yards, and hitting the point aimed at with almost the same precision as a gun. In the same manner there is no doubt the submarine boat will be improved, while there is a great field for development in connection with the secondary battery. Here, indeed, as in many other respects, one finds that close interchange of interests between the mechanical engineer and the artillerist, which affords some justification for bringing before this Institution a subject of such great interest to the profession, fraught as it is also with such vital importance to every citizen.

The Paper is illustrated by Plates 63–95 and 3 Figs. in the letterpress.

The author exhibited at the Meeting a number of working models of breech-mechanisms, &c.

Discussion.

The PRESIDENT thought the Members were indebted to the author for a Paper of very great interest and value, which would aid them materially in understanding many of the things they would see when visiting the works of Messrs. Vickers, Sons and Maxim.

He had much pleasure in proposing a most hearty vote of thanks to the author for the trouble he had taken in preparing his most useful Paper.

Lieut. DAWSON, in reply, having thanked the Members for their kind vote of thanks, said he was much honoured at being asked to read a Paper before the Institution.

Mr. E. R. DOLBY asked the author to explain how the threads were cut upon the double-threaded breech block.

Mr. GEORGE ADDY said that about ten years ago he had had a little experience with armour-piercing projectiles, and at that time caps had not been thought of for assisting the penetration. He hardened some forged steel projectiles for Messrs. Sir W. G. Armstrong, Mitchell and Co., of Elswick, which, on being fired from a 4·7-inch gun, passed through an armour-plate practically without being marked; although in passing through the projectiles "jumped up" perhaps $\frac{3}{16}$-inch, the distortion was trifling, and if necessary the shells could have been fired a second time. The nose of the shell bore little trace of having been forced through a solid mass of metal, and at first sight it seemed rather difficult to understand how covering up the point of the shell with a metallic cap could assist the projectile in penetrating an armour-plate; he would be glad if the author would throw some light on the subject, and explain how this was effected.

Mr. E. B. **Ellington**, Member of Council, asked what was the thickness of the plate pierced by the shell shown by the author.

Lieut. **Dawson**, in reply, said the cutting of the threads of the screw, Fig. 9 (page 510), presented, in the first instance, some little difficulty, but Mr. Douglas Vickers, the managing director of the Vickers Company, designed a special machine for performing the operation, which, however, was difficult of explanation. The action of it roughly is as follows:—The screw controlling the transverse movement of the saddle of the lathe is removed, and is replaced by two strong springs which maintain a knife-edge on the further end of the saddle in contact with a cam on a shaft revolving at the same speed as the mandril of the lathe. The thread of the screw thus made is continuous, the varying radii of the steps of the screw being controlled by the cam. On rotating the lathe the tool cuts the thread on the lowest step, and, as the tool approaches the second step, the knife-edge is released by the cam and the saddle flies back to the second position by the force of the springs, thus cutting the thread on the larger radius. In the case of breech blocks with more than two steps, this operation repeats itself according to the number of steps on which the thread is to be cut.

It subsequently appeared to be more satisfactory in cutting the screws to cut the threads one at a time by an ordinary form of cutting tool, simply making the machine automatic when it was necessary to cut the thread at one or the other radii, and he believed that machine was now more generally used. His firm would be pleased to explain the various details of the machine to any Members of the Institution who would visit the Sheffield or Erith Works.

He had purposely said very little about the cap projectiles, because up to the present time the British Government had not adopted them, but trials were still being carried out. With regard to the 4·7-inch projectile mentioned by Mr. Addy, there was no difficulty in hardening a shell to pierce an ordinary plate, unless the plate was specially treated by the Krupp hardening process or other processes producing like results. The particular projectile

(Lieut. Dawson.)

to which he referred did not go through an ordinary quality steel plate, but through a carburised plate specially treated in the latest possible way and similar to the plates now being used in the new British battleships and cruisers. It was for that reason he had specially laid stress on a projectile passing through a very high resisting plate without any appreciable setting up or marking on its outside. It would interest the members to know that the type of projectile exhibited was used by the United States of America. Nearly all their new projectiles were being manufactured by a similar process, and fitted with a special form of cap. The cap itself weighed from five to six per cent. of the weight of the projectile, and was put on by hydraulic pressure. An annular ring was cut round the hard nose of the shell, into which the cap was squeezed, a projection being made on the cap in order that it might fit into the annular ring round the shell. The way in which the cap worked was rather doubtful, but he was of opinion that it tended to strengthen the point of the shell by holding the particles of steel together at the moment of impact, and immediately the point of the shell pierced the plate, the cap to some extent acted as a lubricant and eased the passage of the shell through the plate. Of course the actual effect of caps was different and varied according to their construction. The special cap used in the shell he had exhibited was made of a very mild steel, and at the moment of impact no doubt acted as a sort of buffer for the shell, and the inertia of the material in setting back held the point of the shell together. As he had mentioned, the plate at which the particular shell was fired was of special construction, with a carburised face and treated in a special way under the very latest processes used by his firm in Sheffield. As those processes were somewhat secret he could not go into details.

Mr. W. SILVER HALL asked the author if it would not be possible to cut the threads by means of a milling cutter of small diameter.

Lieut. DAWSON said he did not think that up to the present a milling machine had been used for cutting the screws. Messrs.

Armstrong and the Government factory at Woolwich were making similar guns, and he was not sure what methods they employed. In the particular construction described in the Paper, where a certain amount of space had to be left between the one thread and the other, it might be difficult to get a milling cutter to perform this work effectively.

THE ARRANGEMENT AND EQUIPMENT OF SHIPBUILDING WORKS.

By Mr. JAMES DUNN, of London and Barrow-in-Furness.

Rapidity of production and economy in construction are the two great desiderata of modern shipbuilding. Competition is sufficient explanation of the latter requirement; while a shipowner, although he may take months in which to make up his mind to place an order, accompanies his valued communication with commands as to delivery and, like Kipling's Midshipman, the shipbuilder "must do what he is told—not immediately but sooner, much sooner." But even a cursory examination into the economics of manufactures convinces one that rapid construction of itself means economical work, for that which ensures the one promotes the other. Modern mechanical appliances, which facilitate and economise work, tend also to reliability in the result; for apart from the influence upon the worker of the precision of machine tools with their gauges, there is in the end a higher remuneration for a given job, since less time is taken and thus there is less temptation to "scamp" work. This latter is more prevalent where the process is purely manual and of long duration.

In the arrangement and equipment of shipbuilding works primary consideration must therefore be given to rapidity in construction, consistent always with a due appreciation of the possibilities of earning profit on the capital involved; this latter is of importance because ideals are usually expensive. For instance, no one will gainsay the great economic advantage of practically completing a ship within a graving dock, because all heavy parts of the structure may be moved by portable cranes to their exact position within the ship, whereas with a ship in a fitting-out basin and a fixed crane the ship must be moved—a process which, in the case of a ship of 10,000 or 11,000 tons displacement, is costly and troublesome. Many may thus consider that the ideal establishment is a shipbuilding yard, whose berths are all or nearly all graving docks permitting the vessels to be completed with the help of gantry or cantilever cranes travelling on the dock walls, the necessary workshops being in juxtaposition, so as to minimise the distance through which material has to be traversed. A graving dock, however, involves a capital expenditure of quite £100,000, and the interest and depreciation would thus become a heavy charge which might exceed the resultant saving. Moreover, it is not always possible to have even a limited number of berths filled with ships of great labour value. A compromise must therefore be made, and a fitting-out basin as well as a building slip becomes necessary.

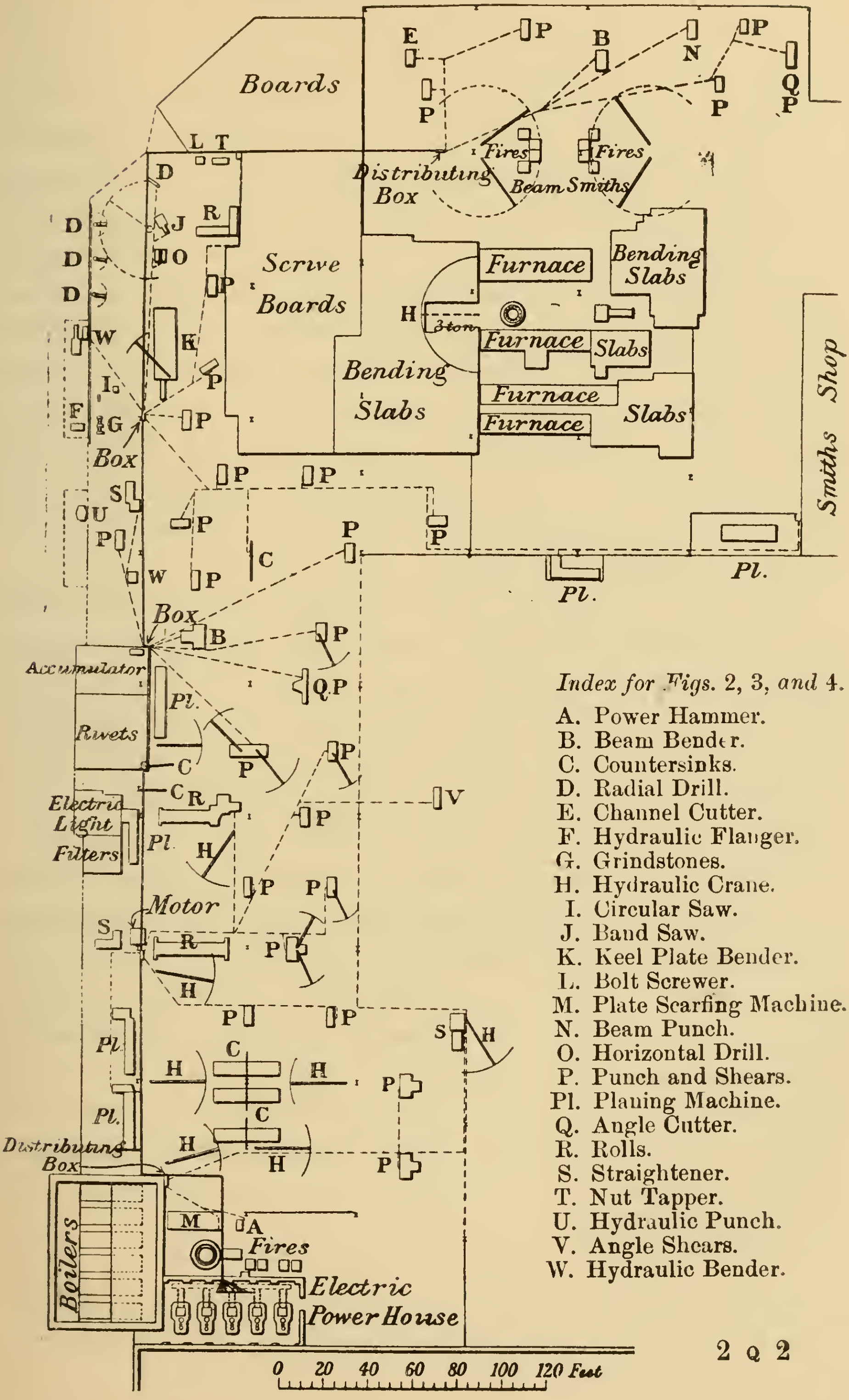
General Principles Dominating the Plan of Shipbuilding Works (*Plate* 96).—The nature of the site available influences the arrangement of the works, but the general principle dominating the plan is that the various departments must be arranged in relation to the ship at radii increasing in direct proportion to the lessening importance or volume of the work turned out by the respective shops for the ships when on the building slip, or when at the fitting-out basin. Thus, the platers, angle-iron, and beam workers must necessarily occupy the closest position to the ship, beyond them would come the joiners and wood-workers generally, while in the third zone there would be the light iron and copper constructors with various other departments, as for instance upholstering, decorating, etc. It is desirable, too, that the engineers and boiler makers should not be far removed, for as much as possible of the machinery weights should be put on board a ship before it is launched. A new set of conditions arises when the ship is at the fitting-out basin; then the minimum of steel structural work remains to be done, while the cabin fitting, decoration, and engineering work predominate.

Plate 96 is a plan of the Naval Construction Works of Messrs. Vickers, Sons and Maxim, at Barrow-in-Furness, first laid out by the late Mr. Robert Duncan, of Port Glasgow, upon such a well-defined and liberal plan that, notwithstanding great expansion during the past three years, there has been no need to depart from the general scheme, which will be recognised on all hands as admirable even in the light of present-day experience. In the shipbuilding yard (the section of the works to the north of the Ferry Road) the main buildings form a quadrangle, the space within which serves admirably for stacking the plates, etc. The range of shops close to the building slips are occupied by the scrieve boards, angle and plate furnaces, bending blocks, and angle-, beam- and plate-working machine tools, and these are arranged so that the steel structural material passes from the quadrangle through the respective departments in a clearly defined direction, handling being reduced to a minimum. The wood department is confined to the eastern side of the quadrangle, the timber being passed through the saw-mill to the "racks" or to the shops, while the joiners', carpenters', boat-builders' and block and tackle makers' departments (embraced in the one building) have direct communication with the building slips. Again the galvanising, plumbers', smiths' and engine-fitters' shops, to the west of the quadrangle, are all arranged as near to the building slips as the steel workers' department will admit. For new building berths there is available ground to the north-west, and as a separate entrance for material coming by railway has been arranged, along with stackyard and cantilever travelling-crane for distributing the steel, it will only be necessary to add steelworkers' machine sheds to the west, still retaining the furnaces and bending blocks in the central position.

The site available, tidal influences, and the harbour plan, largely influenced the relative positions of the engine-works and the shipbuilding yard, but the result attained is distinctly satisfactory. The engineering department with the shipbuilding yard together form an oblong on plan, the fitting-out basin being at the one end and the building slips at the other. As the maximum of steel structural work is done before the ship is launched, the amount of time lost in transit, both of workers and material, is very small in this important department. This is assisted also by the various departments engaged in the ultimate completion of the ship having workshops close to the fitting-out basin, and also by having on board the ship many portable machine-tools, so that the movement of men and material between the shipyard and the fitting-out basin is comparatively small. Indeed, careful calculation has shown that the loss involved in this way at the Barrow Works is probably only about one-sixteenth of 1 per cent.: in an establishment where the ships are fitted out at a distance of about half a mile from the works the loss for transit has proved in one actual case to be 4·6 per cent. on the work done at the fitting-out basin. This practice of completing the vessel away from the shipbuilding base is a common practice both on the Clyde and on the Tyne.

The Electric Driving of Machine Tools (*Fig.* 2).—Turning now to the arrangement and driving of tools, a plan of the plate, angle, and beam tool shops is given, Fig. 2, which shows also the position of the electric power station and circuits. Importance from the economical point of view must be attached to the electric driving of machine tools, and at the Naval Construction Works the installation is very complete. The power station consists of five generating sets, the total horse-power being 1,250, and the electrical capacity 750 kilowatts, but in the engineering and gun-mounting department the power plant is of 2,500 horse-power and 1,500 kilowatts capacity, and electrical connection is established between the two departments. These stations are utilised both for power and lighting purposes, the voltage of the direct current being 210 with 3,570 ampères in the shipyard department and 7,150 ampères in the engineering works. As to the economy of the electrical system the coal consumption over a given period of average working conditions is only one-third what it was for steam driving, but the interest and depreciation of the electrical equipment must be taken into consideration. This, however, is not likely to equal the coal economy, while there is the additional advantage of direct control over the motors.

FIG. 2.—*Plate, Angle, and Beam Tool Shops in Shipyard. Arrangement of Electric Power Station and Circuits.*



Index for Figs. 2, 3, and 4.

A. Power Hammer.
B. Beam Bender.
C. Countersinks.
D. Radial Drill.
E. Channel Cutter.
F. Hydraulic Flanger.
G. Grindstones.
H. Hydraulic Crane.
I. Circular Saw.
J. Band Saw.
K. Keel Plate Bender.
L. Bolt Screwer.
M. Plate Scarfing Machine.
N. Beam Punch.
O. Horizontal Drill.
P. Punch and Shears.
Pl. Planing Machine.
Q. Angle Cutter.
R. Rolls.
S. Straightener.
T. Nut Tapper.
U. Hydraulic Punch.
V. Angle Shears.
W. Hydraulic Bender.

As the power necessary for the various types of machine tools was most carefully investigated when the system was introduced, it may be useful to the Members of the Institution to have a list of the machinery in the shipbuilding yard with a note of the power of the electric motors installed for each tool, and this is given in Appendix I (page 582). Where the tools are conveniently situated for driving from shafting—as a rule where belt drive was formerly adopted—the shaft has been retained and a large electric motor conveniently placed for running it. This secures any advantage obtainable from stored-up power in the pulleys to assist in starting drills and cutting-tools generally, while at the same time a less power of motor is possible, since all the machines are not likely to be simultaneously doing their maximum duty. In the machine shed, however, the majority of the tools have independent motors, the largest being 45 horse-power operating plate-bending rolls 30 feet long to take in protective deck plates, while there are several cases of from 30 to 20 horse-power motors.

Many of the motors drive their machine tool by belting with belt-striking gear for reversing. Some of the punching and shearing machines, however, are driven by spur gearing, the pinion on the motor spindle being of soft material, to deaden the shock and reduce the vibration. In such cases the motor is itself reversible. In a few instances—for large mangle rolls, angle shears and angle bevelling machine—a chain belt covered by a gear case is used.

As to the speed of the motors, all above 5 horse-power run at 600 revolutions per minute, the interposition of belt pulleys enabling the speed of the various machine tools to be reduced to the required rate of rotation. Motors of 3-horse-power, which are used for drilling, counter sinking, joiners' saws, &c., are run at 850 revolutions. The 2-horse-power motors, of which there are three or four, run at 1,200 revolutions per minute, two 1½-horse-power motors make 1,100 revolutions per minute, while several 1-horse-power motors, used for grinding, for saws and for several portable tools, make 1,300 revolutions per minute.

The Arrangement of Machine Tools in the Platers' Shed (*Figs. 2 to* 4).—The arrangement of the tools generally is indicated on the

FIG. 3.—*Arrangement of Machine Tools in Platers' Shed, Shipyard.*

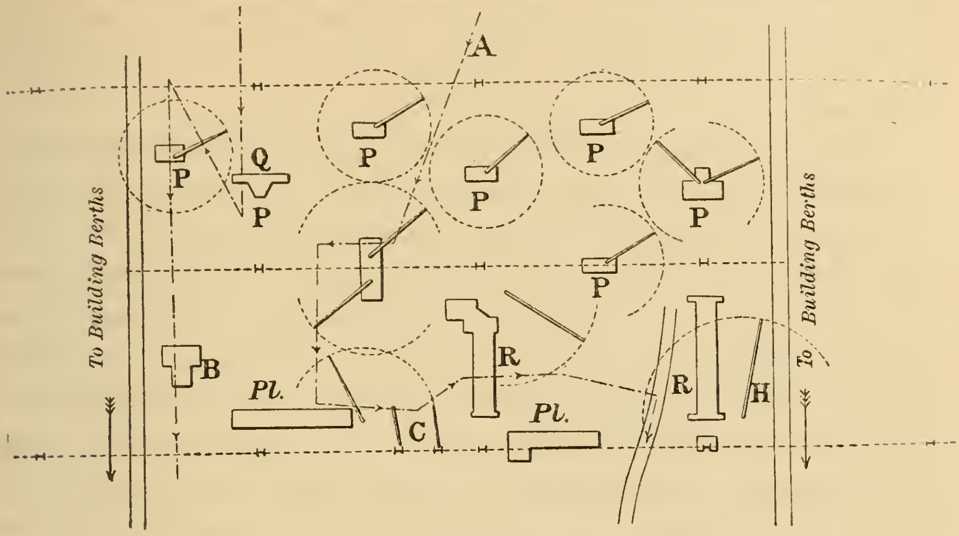
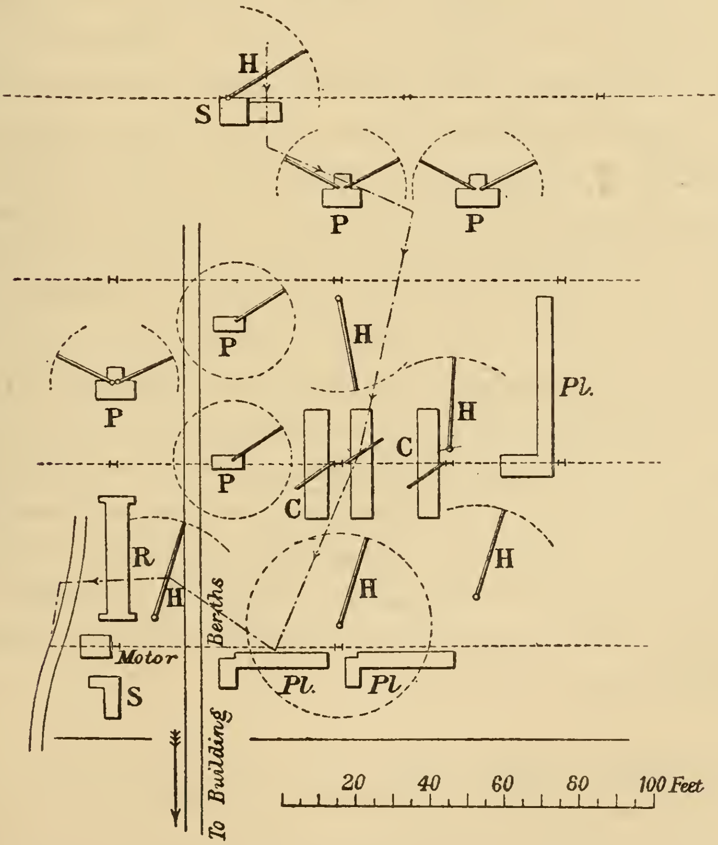


FIG. 4.—*Another Arrangement.*



Dotted line with arrow heads indicates the direction of Plate or Beam passing through the machines. (For Index to lettering, see page 559.)

plan of the plate, angle, and beam tool shops, Fig. 2 (page 559). It will be seen that beams are worked on separate slabs and machined to the west of the furnaces, angles to the south, and plates in the main shop.

Figs. 3 and 4 (page 561) show more fully a typical arrangement of machine tools in the platers' shed, and dotted lines and arrow heads indicate the direction of the plate or beam through the machines. The plate, it will be seen, enters from the quadrangle at A, Fig. 3, and passes to one or other of three large punching machines P, where it is also sheared, going next to a plate-edge planer Pl, to the counter-sinking machine C, and finally through the rolls R to the railway, having direct communication with the building slips. The direction of the beam is also defined through the angle-cutter Q, beam-punch P and bender B. A similar diagram, Fig. 4, shows in another group of tools the same wide area around the tools to ensure that the work at one machine may not interfere with the operations at another, while heavy plates can be transferred by cranes successively from one machine to the other, being delivered ultimately close to the ship. It is of great importance to have cranes of wide radii and other plate-shifting facilities. It is just possible that in this department an improvement could be effected in the handling of plates by the adoption of the system in use for a similar purpose in some of the rolling mills of the United States. Small posts are placed at occasional intervals in the rolling-mill shop floor, having castors or rollers at the top arranged to swivel in every direction : the system has been aptly described as corresponding to tables inverted, so that the castors on the legs are uppermost. With such an arrangement of uprights the plate could easily be run from one machine to the other, or from end to end of the platers' shop by the gang of men working it through its successive operations. The level at which the plate is fed into the several machines would require to be exactly the same in all cases.

Some Large Machine Tools (*Plates* 97 *to* 99).—It is scarcely necessary to say that at the Naval Construction Works every conceivable type of ship is built, and Messrs. Vickers, Sons and Maxim have therefore installed very powerful tools. Drawings are given of some of the heavier tools, principally to show their scantlings. Plate 97 illustrates a set of mangle rolls to take plates up to 6 feet wide. There are at the works also rolls for straightening and shaping plates 30 feet long, the large top roller being elevated and depressed by an electric motor at each end, while the driving and reversing of the machine is done by a 45-horse-power motor with a reversing switch. Plate 98 shows a hydraulic bender and flanger fitted with cylinders of sufficient power to bend—when cold—plates $\frac{7}{8}$-inch thick and of any length up to 32 feet. The tool shown by Figs. 9 and 10, Plate 99, is a scarfing machine for tapering ship-plates at the edges so that they may overlap to obviate the fitting of tapered liners, three-ply riveting and the caulking of same. The operating of the cutting-tool will be easily followed by a reference to Fig 10.

A hydraulic machine is shown by Fig. 11, Plate 99, for cutting channels and angles; it is operated on the principle of the hydraulic press. There are also one or two other hydraulic machines, notably one for punching man-holes. The hydraulic power for all tools in the yards is developed in a separate power plant working up to a pressure of 1,600 lbs. to the square inch. In Appendix I (page 582) a complete list of the principal tools within the shipbuilding yard is given, and no further reference is here necessary.

Closed-in versus *Open Shipbuilding Berths and the Cranes serving them* (*Plates* 100 *and* 101).—The increase in the size of ships, the greater weights of the units now used in construction, and the extension of the practice of counter-sinking, riveting, and caulking by portable mechanical tools, have necessitated an improvement upon the old method of rigging up derricks alongside the ship for lifting weights on board, or carrying the tools. Many systems for accomplishing this end have been adopted, and most have advantages to commend them.

One of the first was that in use at Messrs. Harland and Wolff's, Figs. 12 and 13, Plate 100. The gantry crane illustrated has a clear headway from rail level to the underside of the cross-girders of 98 feet, while the clear width is 95 feet. For the purpose of lifting weights on board, separate jibs are carried on each of the four corners of the structure, swinging through an angle of 180° and able to place their load of 4 tons within the shell of the ship, 40 feet distant from the axis of the jib, without moving the crane. The gantry is used primarily for the carrying of hydraulic riveters, and only incidentally for traversing with loads to their position within the ship, so that it would seem that this large structure is limited in its utility. For carrying the hydraulic riveters there are three hydraulic travelling-cranes running on the cross-girders, two of them on the upper and one on the lower boom, an arrangement which enables two riveters to be brought closely together. In the building of the "Celtic" the heaviest weight carried by the travelling-crane gear was understood to be the hydraulic riveters of 7½ tons, and the heaviest weight lifted by the jibs was 3½ tons: at the Barrow Works, 15-ton loads are dealt with in building warships on the slip. With their gantry Messrs. Harland and Wolff were enabled to rivet expeditiously and economically the top-sides and keel plate, the centre plate, the tank intercostals, and flange plate frames and the upper deck stringers in the "Celtic," while similar work is done on other large ships. The thickness of the plating may also be given in connection with the weights requiring to be dealt with in large merchant work: the shearstrake plates of the "Celtic" were 1¼ inches, side plating 1⅛ inches to 1 inch, the bottom plating 1 inch, and the keel plate 1⅜ inches.

The system carried out at the Union Iron Works at San Francisco is shown in Fig. 14, Plate 100. Here are overhead cranes travelling the full length of the building berth, and a series of independent jibs for carrying the girder on which the hydraulic riveter is supported. This involves an extensive structure, the foundations of which on either side limit the number of shipbuilding berths for a given width. The berth is not closed in, but the number and the great sectional area of the trusses for supporting the travelling crane affect the lighting of the berth. These trusses, with their supporting posts, are placed at 12 feet centres; the uprights are utilised for the staging, and they carry, with the use of suspension rods, a jib on which a trolley runs for supporting the girder carrying the riveting machines. The girder and riveters have to be moved from one pair of jibs to the other as required. The weight of the heavier riveters in use is only 1,400 lbs., to work $\frac{7}{8}$-inch rivets with a 30-inch gap. The travelling cranes have a lifting capacity of 5 tons; the speed longitudinally is 180 feet per minute, horizontally 90 feet, and for elevating 90 feet. The structure seems elaborate for the duty done. This system of two cranes placed alongside each other involves a considerable increase in the strength of the truss at the centre to support one half of the crane and its load. In the case of the San Francisco structure another objection has been ingeniously overcome; usually the two cranes are equal in length, and because of their supports there is a considerable space at the centre line of the berth—just over the keel—right fore and aft, over which the crane has no direct control. But, as will be seen from Fig. 14, the apex of the truss is 3 feet from the centre line, and thus the crane to the right of the section is 6 feet longer than the other, and commands the keel. At the same time there is still a small section of the width of the ship which is not commanded by the cranes overhead.

Fig. 17, Plate 101, illustrates a structure which has been erected quite recently at the Vulcan shipbuilding yards at Stettin, and here also the cranes are made of different lengths. The structure is of steel-work without roofing, and the motors are electrically driven. Each crane lifts 4 tons, and the speed of longitudinal traverse is 262 feet per minute.

Neither the berth at San Francisco nor either of those at the Vulcan works in Germany is closed in, and in this respect they differ from the arrangement adopted by Messrs. Swan and Hunter, who, like one or two foreign firms, prefer that the berths should be roofed over, as shown in Fig. 18. There are advantages in such arrangement where severe weather conditions obtain, especially where the snowfall is considerable or the rain incessant for long periods; but apart from the great cost, in view of the loads to be supported, there is always the disadvantage of restricted light, because glazing cannot always be kept clean, artificial light is at best a poor substitute, and the general result may be conducive to idleness. There is also the probability of draughts, and although it is said that this has not been experienced to any great extent at Messrs. Swan and Hunter's, the possibilities are that in wind-swept Barrow this solution might involve inconvenience and discomfort. It is claimed for these structures that there is a saving in the cost of shoring and fairing the vessels, but such economy need not be confined to this particular form. Messrs. Swan and Hunter have provided large horizontal jibs to their travelling cranes, which revolve below the cranes, but withal there is a gap in the centre line. The outside crane of the cantilever type commands a space 500 feet in length and 65 feet in breadth.

Fig. 19, Plate 101, illustrates a German design for building berths. Here also the jib is carried below the main traversing-crane, being suspended in a ball bearing; the horizontal pressure is taken up by live rollers. The lifting gear consists of a double set of spur wheels and a rope drum with turned grooves. The crane has a capacity of 3 tons, the lifting speed being 66 feet per minute, the longitudinal traverse 197 feet per minute, the horizontal traverse 108 feet per minute, and the rotating of the horizontal jib 295 feet; the lifting motor is of 20 horse-power, and the motor for horizontal traverse 13 horse-power. But here again the load is comparatively limited, and there are between 4 and 5 feet in the centre of the ship which are not commanded by the crane.

These overhead systems generally involve a light-excluding structure over the ship; and, most important of all, the maximum weight lifted is not great. While they give the advantage of two cranes for each ship, these are limited in their radius across the ship, although this may not be a serious objection, especially with twin screw steamers. The Wellman - Seaver Engineering Co., of Cleveland, Ohio, who have fitted in some American lake yards gantry-cranes of the cantilever type corresponding in general arrangement with the Brown system, have made an arrangement overcoming this difficulty by overlapping the travelling cranes, and supporting the lifting trolley on the lower flange of the girders forming the travellers, Figs. 15 and 16, Plate 100.

Cantilever Cranes at Barrow (Brown's) (Plates 102 *to* 104).—The system which has been adopted at the Naval Construction Works at Barrow-in-Furness is that known as the Brown Patent Balanced Cantilever type, and a section of the building berths is shown on Fig. 20, Plate 102. This system consists of a light trestle work placed between two shipbuilding berths on which there travels a crane, whose cantilever arms stretch over the ship on either side of the trestle. The trestle for one of the cranes is 729 feet long, and it will be some time before ships exceed this length; the other is 647 feet, and both can easily be extended at any time without even temporary inconvenience. The whole of the ship is immediately under the control of the crane hook, the total span or outreach of the hook being 190 feet, while the clearance above the deck structure is equal to the depth of the ship itself. The same principle is applied for dealing with the plates, timber, etc., at the part of the works where the material is stored, as shown on Fig. 21, Plate 102, the outreach of the hook being 318 feet.

In the design of the Brown cranes as fitted at Barrow the wind area was reduced as much as possible, so as to minimise the constructional material for a given maximum strength. This also lessened the cost, and incidentally admitted the fullest measure of daylight. The trestle has also been designed to avoid interference with operations along the side of the ship. The uprights are attached to their foundations and to the cross connections at the top by pin joints, so that the entire structure may expand or contract longitudinally. The members of the structure are held vertically by the centre panel of the trestle, which consists of a large A brace extending upwards from the foot of one column to the centre of the panel and down to the foot of the other column. Fig. 22, Plate 103, shows the form of this bracing. The only possible interference with the work alongside of the ship is at the uprights where the ship attains its maximum breadth, and even here it is small.

The crane is worked by one 85-horse-power electric motor, Fig. 23, with suitable gearing for the several movements. For traversing the crane along the track on the trestle, power is transmitted through bevel gears and shafting to the driving gears on the truck, which is controlled by suitable brakes and clutches. The trolley travel along the cantilever arms is accomplished by the revolving of two drums winding wire rope connected to the trolley. These two drums are on one shaft which runs always in the same direction. When one drum is thrown into gear with the driving shaft the other is disconnected and remains idle, so that while one winds the other "pays out." The drums are kept in the same relative position to one another by the use of a return loop or a small wire rope, which is wound in an opposite direction to the ropes connecting the trolley. The hoisting is accomplished by a single drum; the lowering is through gravity alone, governed by brakes. The speeds vary according to load with the following maxima:—

Hoisting	100 to 600 feet per minute.
Trolley or transverse travelling .	400 to 800 ,, ,,
Track or horizontal travel . .	400 to 700 ,, ,,

The cranes lift 16,800 lbs. (7½ tons) at the extreme travel of the trolley, and 30,000 lbs. (about 13½ tons) at a distance of 60 feet from the centre of the crane. The resultant force of the crane under the load is kept within the proper limits by the use of a counterweight running on a track along the cantilever arms and above the track on which the hoisting trolley travels. It is connected by ropes to the trolley, so that whatever may be the position of the hoisting trolley on one arm of the crane the counterweight is at the same time automatically brought to a similar position on the other arm. For extra heavy loads there is an additional weight which is added with little trouble to the normal counterweight of 4,000 lbs. To raise heavy loads at 60 feet from the centre the counterweight is adjusted so that instead of being 60 feet it is 90 feet from the centre, or at the extreme of the opposite arm. This is easily accomplished: the trolley is brought to the centre of the crane, and the counterweight automatically also comes to the centre; the counterweight is then unclamped from the ropes which connect it to the travelling trolley, and the trolley moved out 30 feet on the cantilever opposite to that on which the heavy load is to be lifted, and the counterweight is there re-clamped. This operation occupies but a minute or two. Thus when the lifting trolley travels to the load it passes through 90 feet in coming from 30 feet on one side and going to 60 feet out on the other arm where the load has to be raised. The counterweight naturally travels simultaneously through its 90 feet, which will be from the centre to the extreme of the arm opposite to the load. Thus the full lever arm is utilised and the full effect of counterweight obtained.

Fig. 21, Plate 102, and Fig. 25, Plate 104, illustrate one of the Cantilever Yard Cranes. The main point to be noted in the construction of these cranes is the open trestle structure, allowing pieces of 60 feet in length to be carried through the pier without turning. To avoid twisting there have been adopted what really amounts to two trolleys, which carry their loads at two points, and which travel at exactly the same speed. Actually, however, these two blocks form part of a single trolley which is operated by two drums. The rope system employed is somewhat complicated, but the diagrams, Fig. 26 (pages 570 and 571), for which the author is indebted to the Brown Co., indicate the general method of weaving the lines. The capacity and dimensions of the yard cranes are as follows:—

Trolley travel 159 feet 1½ inches each way from the centre of the crane, or, in other words, a total of 318 feet 3 inches centre to centre of the extreme position of the hoist block.

The maximum load is 11,000 lbs. (5 tons), which can be lifted and travelled through the entire length of the travel of the trolley on the runway.

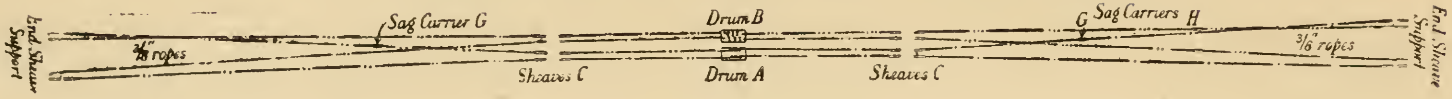
The double tracks on which these cranes run are gauged 30 feet 6 inches centre to centre.

The power which is necessary to run one of these cantilevers is 85 horse-power arranged for 200 volt tension direct current.

The motor will lift the maximum load 11,000 lbs. at the rate of 200 feet per minute, will traverse the crane along the tracks at about 300 feet per minute, and travel the trolley to any desired speed up to 750 feet per minute.

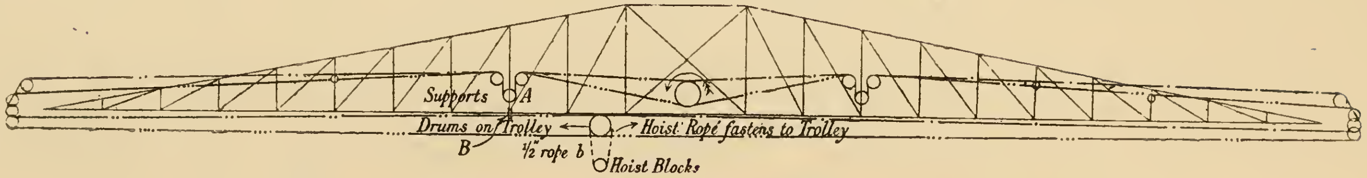
FIG. 26.—*Diagram of Rope Leads.*

Plan view showing lead of ropes from engine to end sheave supports.



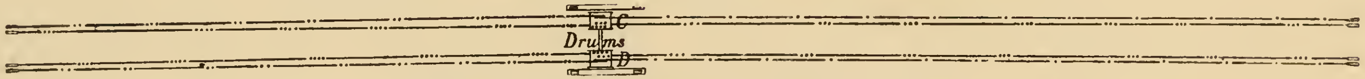
Operator's house this side.

Side elevation looking from operator's house.



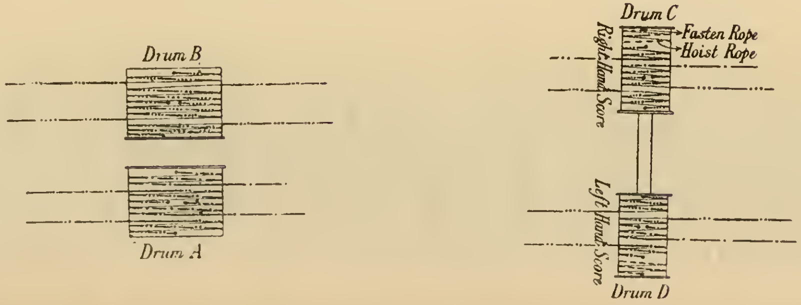
To hoist load both engine-drums, turn in direction indicated by arrow.

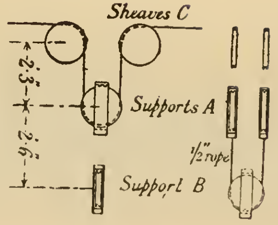
Plan view showing lead of ropes from end sheave supports to trolley.



This side of trolley nearest to operator's house.

Diagrams showing order in which ropes fasten to trolley drums.





NOTE.—When rieving ropes fasten sheave supports A and B in position shown with reference to sheaves C.

Ropes required per crane.

"a" 8 ropes $\frac{3}{8}$-inch plough steel 625 feet long. Socket at one end, to be put on in field.
"b" 2 ,, $\frac{1}{2}$-inch ,, ,, 80 ,, ,, ,, ,, ,, ,, , eye and bent plate at one end, put both fastenings on in field.
"c" 4 ,, ,, ,, ,, 5 feet 3 inches long. Sockets both ends, put on in fields.

Ropes "a" are main ropes running from engine to trolley. Ropes "b" are hoist ropes on trolley. Ropes "c" are tail ropes connecting each pair of sheave supports "A."

When the trolley drums are at the centre of the crane and the load is lifted half-way up, all ropes "a" have the same length on drums A and B.

When the load is lifted to the limit of its motion, ropes —·— and —···— have 1½ turns each on trolley drums C and D, the $\frac{9}{16}$-inch score for the $\frac{1}{2}$-inch rope "b" is full, and the remainder of drums C and D is full of ropes —·— and —··—

To adjust ropes.

Run the trolley to the centre of the bridge and shorten the ropes by means of adjusting screws at sheave supports C, until the rope —··— and —·— have about 4 feet sag in the span from the trolley to the end of the bridge.

In adjusting ropes, adjustment should be obtained by using the screws in both sheave supports C.

To rieve ropes.

When rieving ropes run the trolley to the limit of its travel at that end of the bridge which is to the right of the operator as he stands at the levers and facing the bridge. Fasten trolley drums so that they cannot revolve. Put on the $\frac{1}{2}$-inch hoist rope "b," first giving it two turns on the trolley drum, when the centre of the hoist block is hanging 28 feet below the centre of the trolley drum. Leaving the hoist blocks in the position just noted, each of the eight $\frac{3}{8}$-inch ropes will have the following turns on the trolley drums and engine drums respectively:—each rope marked —·— will have 11 turns on the trolley drum and 27 turns on the engine drum; each rope marked ·····— will have 11 turns on the trolley drum and 1½ turns on the engine drum. For the ropes marked —·— and —···— put on as many wraps on both engine drum and trolley drums as the number of scores on the drums will allow without overwinding; this will give about 2 wraps for each of these ropes on the trolley drums. For the ropes —··— one will have about 6 turns on engine drum and the other about 11 turns. For the ropes —··— one will have about 31½ turns on the engine drum and the other about 37 turns.

The high speed of horizontal and longitudinal traverse of the cantilever system in operation at the Barrow Works more than compensates for the duplication of cranes in the instances already indicated.

The Utility of Building-Berth Cranes.—It will be seen that these cantilever berth cranes serve all the purposes for lifting material on board, while as regards the supporting of hydraulic riveters for double bottom and keelstrake work, the usual method of a gantry running on the inner bottom or flooring of the ship will, as formerly, be applied. For supporting the riveter for working the bilge and sheerstrake, there is no reason why jibs should not be carried on the trestles of the cantilever cranes, and on special uprights on the offside of the ship; the pneumatic tools for riveting, caulking, etc., are easily supported upon the deck beams because of their light weight.

The primary consideration was to secure a wide radius of action and a reasonably large lifting power at high speed, because of the important desiderata which were indicated at the commencement of this Paper, and particularly because of the economy which results from the lifting of as much of the machinery and internal equipment on board while the vessel is on the slip. Thus, for instance, it becomes a simple matter in the future to put on board quickly and thus economically all auxiliary machinery, the greater part of the water-tube boiler equipment, the bed-plates of the main engines, the shafting right up to the thrust block, and many other details. It is true that part of this work has been done in the past, but it has been accomplished at considerable cost with temporary sheer-legs which had to be moved from time to time. The principal limiting condition to the work done before floating the ship is the ultimate weight to be launched. In the first place there is the load on the launching ways, which has not hitherto exceeded to any extent 3 tons per square foot, but it is more frequently less than 2½ tons, so that there is from this point of view still some possibility of increase. Again, the dip of the stern of the ship at launching is a determining factor. At the launching ground at Barrow however there is sufficient margin for carrying out the ultimate aim.

Work Done on Various Types of Ships Before and After Launching. —As to the condition of the work at the date of launch, some data applicable to various types of ships have been collected from works where the practice does not materially differ. The data are given in Table I (pages 578–581). This Table gives the total number of men-hours involved in the construction of various types of ship divided between the shipyard and engineering departments; although not germane to the immediate subject in hand, it is interesting to note that, whereas with armoured war-vessels the number of men-hours per ton of totalled finished weight of the ship varies from 678 to 722, the proportion in the case of the fastest of the merchant steamers included carrying a large number of passengers is only 401¼ men-hours per ton weight of the finished ship, while in the case of the purely cargo-carrying steamer it is 240 men-hours per ton weight of the ship. In other words, for a first-class ironclad the number of men-hours is about six million, whereas in the case of a passenger steamer of the same total weight when she leaves the builder's yard the number of hours involved is only about one-half, or 3,310,650 hours.

The proportion of work done by the engineering department varies but slightly—from 24 to 30 per cent. of the total. The case of No. 2 Warship, where the proportion of engineering work is 30·6 per cent., is exceptional, as here an engineering trade dispute influenced the figures. Again, in the purely cargo steamer, column No. IV, the engineering proportion is high, namely, 31·1 per cent., because the shipbuilding work does not involve any extensive internal fittings, owing to few passengers being carried, while the engine power is as great as in the ship No. V in the Table.

As to work done before launching, engineers and boiler-makers, in the case of five of the six vessels, did less than 2 per cent. of the total; the other instance, that of the ship in column No. V, approximates more closely to the condition that will prevail for the future at the Barrow works, for here, as shown in the "condition of the ship at launch," the propellers and tunnel shafting, thrust block, and most of the auxiliary machinery, were on board; but, being a cargo ship, the amount of auxiliary machinery was not by any means so great as is the case in war vessels, and thus the proportion is less than it will be with war vessels. In the case of this vessel in column No. V, however, 10·9 per cent. of the total engineering work involved was completed before the ship was launched, whereas in the warships the percentage was about 2¾ per cent. There seems no reason why this percentage should not be brought up to about 20 per cent.; for although the main machinery cannot be "lined up," owing to possible alterations in the form of the ship when afloat, there are many details and loads which come within the carrying weight of the cantilever crane.

The Table also shows the extent of the shipbuilding work done prior to the launch and also after the ship has been floated. It is important to reduce the amount that requires to be done after launching, because then the ship is further from the shipworkers' base. Much of the work, it is true, involves little or no weights, so that the question of crane accommodation is not so important. It will be seen that with armoured warships the proportion of shipyard work remaining to be done after the launch is between 27·5 and 31 per cent. of all the shipwork; but it varies very considerably in the merchant work, the direct cause being the quantity of joiner and cabinet fittings involved in the completion of the passenger accommodation. Thus in the case where only 9·5 per cent. of shipwork remained to be done (in the ship given in column No. V) the joiner work was three-fourths completed, and all the decks were laid before the launch, whereas in the ship in column No. VI, where 592 passengers are carried, the joiner work was only half completed, and this 48 per cent. of the shipyard work remained to be completed after the launch.

Portable Tools used on Ships (Figs. 27 *to* 29, *Plate* 105).—To expedite work on the ship when on the slip and also in the fitting-out dock, a large amount of portable mechanical plant is used, including a portable electric lighting equipment, an installation of pneumatic riveting and caulking tools, and various electrical drills, etc. It is not necessary to describe these tools in view of the Paper recently contributed to the Institution.* A portable tool which may interest the members is the machine for planing the gun roller paths on barbettes for 12-inch and 9·2-inch guns; this is clearly shown on Fig. 27. It is rotated by a 5-horse-power electric motor, and, with a feed of $\frac{1}{4}$ inch per revolution, the machine cuts at a rate of 15 feet per minute, equal to 20 square feet per hour. Figs. 28 and 29 show a similar machine for dealing with the roller paths of smaller guns of 6-inch and 4·7-inch calibre. This machine is driven by a 3-horse-power motor.

Cranes at the Fitting-Out Basin (*Plates* 106 *and* 107).—Another question which has had to be considered by those responsible for the equipment of shipbuilding works is the type of crane necessary for placing heavy weights on board the ship in the fitting-out basin, and, in addition to showing the general arrangement of the Naval Construction Works' 120-ton crane operated by hydraulic power, Fig. 30, Plate 106, there are reproduced general elevations of four other typical cranes. The heaviest weight lifted in mercantile work within the author's experience is a boiler of over 110 tons weight; with the adoption of water-tube boilers, gun mountings and guns now provide the greatest loads in naval work, and these range from 50 to 60 tons.

The tendency at present is in favour of a derrick crane in preference to sheer legs, because the latter are slow in their movements, work only in one plane and thus necessitate frequent movement of the ship, while the foundation usually involves trouble because the weight carried is concentrated at two points each of limited area. Again, the overhang is not greater than with jib or swing cranes, and now that the tendency is all towards an increase in the beam of ships this latter becomes of primary importance. For instance in three of the largest works the overhang is 60 feet, 57 feet and 47½ feet. In this country there are several types of splendid jib cranes, and reference may be made to the two 130-ton steam cranes by Messrs. Cowans, Sheldon and Co. used by Glasgow shipbuilding firms for fitting engines on board their ships, and having an overhang of 45 feet from the face of the quay with the maximum lift.* At the dockyards there is a splendid hydraulic crane by Messrs. Tannett Walker and Co. of 160-ton carrying power with an overhang from the face of the quay of about 50 feet.† Again quite recently Messrs. Doxford of Sunderland installed a jib-crane which can lift 120 tons when the jib is commanding a radius of 50 feet, 70 tons for 80 feet radius and 30 tons for 100 feet radius.‡ But it is of special interest to note what has been done abroad during the past two or three years. Nearly all the works in Germany have been erecting powerful jib-cranes in anticipation of the construction of great cargo steamers. Figs. 31 and 32, Plate 106, illustrate two cranes, the one of 100-ton capacity and the other of 150-ton capacity. Both these cranes are of the horizontal revolving type which enables the jib to turn a complete circle; so that with a jib of about 180 feet in length the radius is very extensive (or 115 feet from the central pivot, as in Fig. 32). On the other hand the clearance above a ship is limited, especially for what are known as the storm-decker steamers with immense funnels.

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* "Portable Pneumatic Tools," by Mr. E. C. Amos, Proceedings 1900, page 119.

The crane shown by Fig. 31 has been constructed by the Benrath Company of Düsseldorf for the Bremen Vulcan Works, and consists of a tower which turns on twelve carriages each running on four rollers, and for rotating purposes four of these carriages are fitted with electric motors of 12-horse-power. The lifting mechanism is also driven by electric power.

The Benrath Company have also constructed a crane for the Imperial Dockyard at Bremerhaven, Fig. 33, Plate 107, with a stationary tower the vertical axis of which is formed by a revolving pillar having its bearings in the foundations and above in the head of the tower. This pillar bears the horizontal jib which is itself symmetrical as regards right and left; the one arm supports the crab, the other a counterweight. The whole turns through 360°, and the crab moves at the same time, so that the area covered by the crane is equal to a circle whose external radius is 72 feet and internal 26 feet. The rotating power is an electric motor of 26-horse-power; the crab traversing motor is of the same power, and the two hoisting motors of 40-horse-power working a steel rope 2·4 inches in diameter with differential pulley and double capstan.

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* "Engineering," 1893, vol. lv, page 819.

† *Ibid.*, 1894, vol. lvii, page 259.

‡ *Ibid.*, 1901, vol. lxxi, page 604.

Messrs. Krupp's crane, built by the Duisburger Company, shown in Fig. 32, Plate 106, differs in that it has a pyramidal structure which occupies less of the quay space than the usual crane, as between the legs railway carriages or large loads may easily be passed, as shown in Fig. 32. The chief structure has the form of a three-legged equilateral pyramid, two of whose legs are placed in a line parallel to the quay's edge; the three chief legs are connected at the top by a closed frame, within which the roller path of the crane pillar is fixed; the pillar forms the central axis of the pyramid; it rests on a roller path at the quay level and is provided with a pivot; this roller path has a special bearing. The mechanism which effects the turning of the horizontal jib is placed on the upper roller path, and the jib projects 125 feet from the central axis and is fitted with two independent winding-gears travelling with their respective crabs; the outer gear lifts 45 tons, the other 150 tons; there is a third small lifting crab. The total height is 150 feet 11 inches to the upper edge of the horizontal jib.

A remarkable derrick-crane has been constructed for Messrs. Blohm and Voss's Works by the Duisburger Company; it deals with loads of 100 tons, and the radius from the centre of the crane for such load is 93 feet 5 inches, giving an overhang in front of the quay of about 65 feet. This crane, which is shown on Fig. 34, Plate 107, lifts its full load at a speed of 4¼ feet per minute, and in addition has separate hoisting machinery for dealing with loads up to thirty tons, the hoisting speed being 13 feet per minute. The great overhang is secured, as in Messrs. Doxford's crane, by arranging that the jib, notwithstanding the great power, can have its inclination altered to a very considerable extent; in Appendix II (page 587) a full description of the crane is given, so that here it is not necessary to enter into details.

The Paper is illustrated by Plates 96 to 107 and 4 Figs. in the letterpress, for the preparation of which the author wishes to express his indebtedness to several authorities, whose names appear on page 588, and to the members of his staff who have prepared the illustrations.

TABLE 1 (*continued to page* 581).—*Labour Involved in the Construction of After Launching in Ship and*

	I. Warship No. 1.	II. Warship No. 2.
	length. breadth. depth.	length. breadth. depth
Dimensions	435′ 0″ × 69′ 3″ × 39′ 9″	435′ 0″ × 69′ 3″ × 39′ 9″
Gross Tonnage	7,056	7,056
Crew	677	677
Passengers	—	—
Indicated Horse Power	16,800	18,200
Aggregate Workmen-Hours on Ship :—		
Shipyard Department	4,344,147 hours	4,290,168 hours
Engineering Department	1,623,837 ,,	1,891,893 ,,
Total	5,967,984 ,,	6,182,061 ,,
Percentage of Shipyard Department to total	72·8 per cent.	69·4 per cent.
Percentage of Engineering Department to total	27·2 ,,	30·6 ,,
Men-Hours per ton of Builder's Finished Weight: Hull	520¼	501
Men-Hours per ton of Builder's Finished Weight: Engines	194½	221
Work Done Before Launching :—		
Total Number of Men-Hours, in both Ship and Engine Works	3,083,348 men-hours	3,159,634 men-hours
Total Number of Hours on Engine and Boiler-room Work prior to Launch	44,527 hours	53,226 hours
Percentage of Engine and Boiler Work to the Total work before Launch	1·4 per cent.	1·7 per cent.
Percentage of Engineering Work done to Total requiring to be done to complete Machinery	2·7 ,,	2·8 ,,

Various Types of Vessels; and the Proportion of Labour done Before and Engineering Work Respectively.

III. Armoured Warship No. 3.	IV. Merchant Ship.	V. Merchant Ship.	VI. Merchant Ship.
length. breadth. depth. 390′ 0″ × 74′ 3″ × 43′ 0″	length. breadth. depth. 440′ 0″ × 54′ 0″ × 36′ 0″	length. breadth. depth. 345′ 0″ × 42′ 0″ × 25′ 8″	length. breadth. depth. 500′ 0″ × 55′ 0″ × 37′ 0″
8,700	6,514	3,080	7,945
750	84	52	200
—	17	74	592
13,500	2,000	2,270	9,140
5,224,309 hours	785,905 hours	582,752 hours	2,382,353 hours
1,653,011 ,,	353,541 ,,	219,217 ,,	928,297 ,,
6,877,320 ,,	1,139,446 ,,	801,969 ,,	3,310,650 ,,
75·9 per cent.	68·9 per cent.	72·6 per cent.	72 per cent.
24·1 ,,	31·1 ,,	27·4 ,,	28 ,,
515	165½	227	288¾
163	74½	85½	112½
3,705,537 men-hours	584,381 men-hours	550,932 men-hours	1,273,175 men-hours
95,439 hours	16,156 hours	23,852 hours	36,418 hours
2·5 per cent.	2·7 per cent.	4·3 per cent.	2·8 per cent.
5·7 ,,	4·5 ,,	10·9 ,,	3·9 ,,

TABLE 1 (*continued on opposite page*).

	I. Warship No. 1.	II. Warship No. 2.
Launching Weight	6,370 tons	6,520 tons
Builder's Finished Weight (including Machinery)	8,350 ,,	8,560 ,,
Percentage of Launching Weight to Builder's Finished Weight . .	76·3 per cent.	76·2 per cent.
CONDITION OF SHIP AT LAUNCH . . .	Iron and steel work practically complete. All armour complete. Decks complete. Joiner work half complete. Plumber work three-fourths complete. Propellers and tunnel shafting on board.	Iron and steel work practically complete. All armour complete except conning tower. Decks complete. Joiner work half complete. Plumber work three-fourths complete. Propellers and tunnel shafting in place.
WORK DONE AFTER LAUNCH:—		
Total number of Men-Hours after Launch — Shipyard	1,305,326 men-hours	1,183,760 men-hours
Total number of Men-Hours after Launch — Engine Works	1,579,310 ,,	1,838,667 ,,
Percentage of Ship Work to Total Work done	45·2 per cent.	39·1 per cent.
Total Number of Hours of Shipyard men after Launch	1,305,326 hours	1,183,760 hours
Percentage to Total of Shipyard-Hours .	30·04 per cent.	27·5 per cent.

TABLE 1 (*concluded*).

III. Armoured Warship No. 3.	IV. Merchant Ship.	V. Merchant Ship.	VI. Merchant Ship.
7,460 tons	3,750 tons	2,120 tons	5,440 tons
10,140 ,,	4,740 ,,	2,566 ,,	8,250 ,,
73·6 per cent.	79·1 per cent.	82·6 per cent.	65·9 per cent.
Iron and steel work practically complete. Side armour on both sides complete. Screen bulkhead forward and aft and lower portion of barbette armour forward and aft complete. Upper portion of barbette armour and conning tower not fitted. Casemates Nos. 1, 2 and 5 on each side not in place. Decks complete. Joiner work half complete. Plumber work three-fourths complete. Propellers and tunnel shafting on board.	Iron and steel work practically complete. Wood decks with exception of flying bridge and deckhouse tops all laid. Joiner work very little done. Propellers and tunnel shafting, thrust shaft, thrust blocks and most of the auxiliary machinery on board.	Iron and steel work practically complete. All decks laid and joiner work three-fourths complete. Propellers and tunnel shafting and thrust blocks and most of the auxiliary machinery on board.	Iron and steel work mostly complete, except building of boat deck, flying bridge, masts and charthouse. Decks seven-eighths complete, and joiner work about half complete. Propellers and shafting including thrust shafts and blocks and most of the auxiliary machinery on board. Plumber work about half complete.
1,614,211 men-hours	217,680 men-hours	55,672 men-hours	1,145,596 men-hours
1,557,572 ,,	337,385 ,,	195,365 ,,	891,879 ,,
50·8 per cent.	39·2 per cent.	22·2 per cent.	56·2 per cent.
1,614,211 hours	217,680 hours	55,672 hours	1,145,596 hours
30·9 per cent.	27·6 per cent.	9·5 per cent.	48 per cent.

APPENDIX I.

LIST OF MACHINES AT NAVAL CONSTRUCTION WORKS WITH POWER OF ELECTRIC MOTORS.

In Mechanics' Shop.

23 Drilling machines to drill from smallest up to 6-inch diameter holes . . . .
20 Lathes (various) from smallest up to 30 feet long by 4 feet 6 inches diameter . . . .
5 Screwing machines, from smallest up to 2½-inch screws .
1 Tapping machine, to tap holes up to 1½ inches diameter .
2 Boring machines, 9 feet long by 3 feet 6 inches diameter .
4 Planing machines, up to 20 feet long by 9 feet high by 10 feet wide . . . .
2 Slotting machines, 10 feet long by 6 feet wide and 14 inches stroke . . . .
2 Shaping machines, 7 feet long by 6 feet wide and 13 inches stroke . . . .
2 Milling machines, 3 feet diameter of tables . . .
1 Grinder for milling machine cutters . . . .
1 ,, for twist drills . . . . . .
2 Band saws for metal cut up to 17 inches thick . . .
1 Machine for setting teeth of saws . . . . .
1 Saw-sharpening machine . . . . . .
2 Pairs of 20-inch emery wheels . . . . .
2 Grindstones . . . .
1 Small blowing-fan for tool smith fire . . . .
1 Emery polishing machine . . . . . .
1 Gas tempering stove and fan . . . . . .
2 2-ton travelling cranes . . . .

All these driven from Shafting by one 30-H.P. Motor.

On Board Ships.

		Motors.
1 12-inch Barbette roller-path façing-machine	Fig. 27, Plate 105. .	5 H.P.
1 9·2-inch ,, ,, ,, ,, ,,	.	5 ,,

		Motors.
1 6-inch Gun seat facing machine	Figs. 28 and 29.	3 H.P.
1 4·7-inch ,, ,, ,, ,,		3 ,,
1 12-pounder ,, ,,		1 ,,
1 Boring machine for protective decks up to 1½ inches diameter		2 ,,
5 Boring machines for armour backing and shells up to 4 inches diameter.		
2 Shaping machines		1 H.P. each.
2 Band saws for metal		1 ,, ,,
2 Circular saws		1½ ,, ,,
4 Drilling machines		½ ,, ,,
2 Emery grinders		2 ,, ,,
4 Grindstones		1 ,, ,,
1 Grinding machine for armour plates		1 ,,
Rotary grinding wheel driven from motor by belt and held to armour by hand.		

In Machine Shed.

	Motors.
6 Plate-planing machines to take plate up to 38 feet by 2 inches thick	10 H.P. each.
1 Large plate-bending rolls, 30 feet long, to take up to 2-inch plate	45 ,,
1 Smaller plate-bending rolls, 20 feet 6 inches long, to take up to 1½-inch plate	30 ,,
1 Smaller plate-bending rolls, 14 feet 6 inches long, to take up to 1-inch plate	10 ,,
1 Large mangle rolls, to take plates up to 6 feet wide (Plate 97)	20 ,,
1 Small ,, ,, ,, ,, ,, 5 ,, ,,	5 ,,
3 Small bending rolls	5 ,, each.
35 Punching and shearing machines, to punch up to 1½-inch holes in 1½-inch plates	5 ,, ,,
1 Punching and shearing machine, to punch up to 2-inch holes in 2-inch plates	20 ,,
7 Bar-bending machines, to bend up to 7-inch by 4½-inch angles	5 ,, each.
2 Hydraulic plate-benders, to bend plates up to 32 inches long by ⅞ inch thick (Plate 98).	
1 Double-headed scarfing machine for overlaps of ship plates (Plate 99)	5 ,,

	Motors.
1 Hydraulic channel-cutter, Fig. 11, Plate 99.	
9 Drilling machines	3 H.P. each.
8 Countersinking machines	3 ,, ,,
1 Double-headed screwing machine 1 6-Spindle nut tapping machine	5 H.P. and shaft.
1 Double geared lathe.	
1 Band saw for metal	2 H.P.
1 Circular saw for metal 6 Grindstones 1 Pair of emery wheels 4 Blast Fans for smith fires	10 H.P. and shaft.
11 Hydraulic cranes.	
1 10-cwt. hydraulic ash-hoist at main boilers.	
1 Hydraulic pumping engine with double cylinders, 12 inches by 24 inches, and accumulator, working pressure 1,650 lbs. per sq. inch.	
1 Pneumatic power hammer, 1 cwt.	5 H.P.
1 5-cwt. steam hammer.	
1 Rumbler for cleaning old service bolts.	
1 Coke-crushing machine	1½ ,,

In Yard.

	Motors.
4 Cantilever cranes (Plates 102, 103, &c.)	85 H.P. each.
2 over shipbuilding berths 190 feet span.	
1 in plate yard 318 feet span.	
1 in timber yard 318 feet span.	

In Smiths' Shop.

	Motors
1 5-ton steam hammer.	
1 1-ton ,, ,,	
3 10-cwt. ,, ,,	
1 8-cwt. ,, ,,	
4 5-cwt. ,, ,,	
5 Drilling machines.	
1 Grindstone.	
1 Blast fan	40 H.P.
76 Fires and Furnaces.	

Heaviest forgings—Rudders up to 17 tons.
Stern frames up to 14 tons.

In Plumbers' Shop.

6 Drilling machines	10 H.P. motor and shaft.
5 Pipe-screwing machines to screw pipes up to 4 inches diameter	
1 Pipe-cutting machine to cut pipes up to 12 inches diameter	
1 Band saw for iron	
2 Punching and shearing machines	
2 Beading and shearing machines, 3 feet gap	
1 Sheet iron rolls to take plates up to 5 feet 6 inches wide	
1 Tinsmiths' rolls „ „ „ „ „ 3 feet wide	
1 Tin-folding machine	
1 Tilt hammer	
2 Blowing fans	5 H.P. each.
1 Boiler and furnace for lead.	
1 Hydraulic boiler tester.	

Boilers, winches, &c.

	Motors.
6 Patent flanges flue main boilers, 28 feet by 8 feet diameter, 160 lbs. working pressure.	
1 Cylindrical, with Galloway's patent flues, 30 feet by 8 feet, for saw mill.	
1 4-Furnace marine boiler, 16 feet by 12 feet diameter, for smithy.	
3 Donkey boilers.	
6 Combined winches and boilers.	
4 Steam locomotive travelling cranes.	
4 Steam winches.	
11 Electric winches	2 25 H.P. each. 4 8 „ „ 1 5 „ „ 4 20 „ „
3 Donkey feed pumps.	
1 Double-acting salt water test pump for testing ships' compartments.	
2 Portable centrifugal pumps, 6,000 gallons per hour	3 „ „
1 Merryweather fire engine.	
1 Portable fire engine for attachment to locomotive cranes.	

In Joiners' Shop.

	Motors.
1 Moulding machine	10 H.P.
1 „ „	5 „

	Motors.
1 Circular saw	10 H.P.
2 ,, saws	5 ,, each.
1 Sand papering machine	10 ,,
1 Cross cut saw	3 ,,
4 Turning lathes	5 ,, and shaft.
1 Pneumatic installation for removing refuse, sawdust, &c., from machines to boiler stokehole, two fans for above	2 20 H.P.
3 Circular saws	Shafting and 1 30-H.P. motor.
5 Emery grinding machines	
3 Spindle and hole cutting machines	
2 Band saws	
1 Grating machine	
9 Dowelling, mortising, dovetailing, &c., machines	

In Saw Mill.

6 Circular saws.
4 Band and frame saws.
2 Saw sharpening machines.
1 Saw setting machine.
2 Travelling benches.
1 Boring machine.
1 Planing machine.
1 Emery grinder.
1 Blast fan for taking sawdust to boiler stokehole.
1 Double compound tandem engine.

All the machines in saw mills driven by above engine.

In Block and Spar Shed.

	Motors.
2 Circular saws	10 H.P. each.
1 Band saw. 2 Turning lathes 3 Boring, Dowelling, &c., machines 1 Grindstone	5 H.P. and shaft.
1 Steam drying stove with two fans	20 H.P.

APPENDIX II.

The description of 100-*ton Derrick Crane*, Fig. 34, Plate 107.

This crane, constructed by the Duisburger Co., late Bechem and Keetman, of Duisburg, for Messrs. Blohm and Voss's Works, Hamburg, was designed to deal with loads of 100 tons, but in order to obtain economical working for smaller loads, the crane has been fitted with two separate hoisting machines and rope tackles for maximum loads of 100 and 30 tons respectively. Each hoisting gear is further constructed for two load speeds, as the following data show :—

Large hoisting gear.

Loads up to 50 tons, lifted at 2·6 mètres (8½ feet) per minute
,, from 50 to 100 tons, ,, 1·3 ,, (4½ ,,) ,,

Small hoisting gear.

Loads up to 10 tons, lifted at 12 mètres (39 feet) per minute
,, from 10 to 30 tons ,, 4 ,, (13 ,,) ,,

The two hoisting gears are driven by a two-cylinder engine with cylinders 9·5 inches diameter and 17·7 inches stroke. The speeds above mentioned correspond to 180 revolutions of the engine. For the trials, maximum loads of 150 and 75 tons respectively were applied. In order to secure the highest efficiency for the hoisting machines worm gearing has altogether been dispensed with; of bevel wheels a limited use has been made, and the main work is done by high-speed spur-wheels with cut teeth. The steel-rope drums and sheaves are of exceptionally large diameters. Each single rope, of both tackle systems, has a guaranteed breaking strength of 100 tons, and the load is held in the large gear by eight, and in the small gear by four, such ropes. The large gear comprises two winding drums, on which two ropes are wound simultaneously; the rope strains are thus equalised. The two hooks turn on glass-hard steel balls, and two joints further permit of their being moved in any direction. As Fig. 34 shows, the jib is not fixed, but its range can be varied within the limits shown. It should be noticed that the small ropes may be loaded with the full 30 tons, and the 45 tons of the trials at the maximum range, whilst the loads of 100 and 150 tons are the maxima for a range limited to 20 mètres. As the centre of the moving jib is only 2·5 mètres from the quay edge, the useful radius of the crane is 32·5 − 2·5 = 30 mètres (98 feet). At *a* the upper part of the jib turns about a horizontal pin, and the whole jib turns horizontally about *b* and *c*. These pivots are borne by a tripod structure. The power for both movements is derived from a second two-cylinder engine, the cylinders being 8·3 inches diameter, by 11·8 inches stroke, placed in the plane *xy*, and the jib inclination is varied with the aid of two screw spindles of Siemens-Martin steel which have their bearings in the tie *d* of the upper pin *b*. The pitch of the screws and the gearing prevent any unintentional sinking of the jib; an automatic brake has further been added lest the jib should yield to concussion. The horizontal stresses of the jib are taken up by the two pins on the tripod structure. The transference of the vertical stresses was a more difficult problem. The frequently applied support of the jib by rollers or balls of steel was inadvisable in consideration of the large forces, and the relatively small basis whose diameter is 4·5 mètres (16 feet). A circular path has been adopted somewhat similar to the construction of the guides of a planing bed. The path base is made of steel, and its circumference is fitted with exchangeable steel bolts, with which the toothed wheels of the two revolving gears engage. These parts are made of great strength on account of the huge masses to be moved and of the wind pressures. When the engine runs at 180 revolutions, the jib turns through 30 mètres (almost 100 feet) per minute, measured on the small hook with maximum radius. The steam-engine does not need a boiler of its own, as the boilers of the wharf are close by. The main steam-pipe is common to both the engines, and it is carried through a stuffing-box into the geometrical axis of the jib, where it is well insulated. The one machinist, who attends to the crane, has his stand in the front part of the jib, at a height of about 23 feet above the flooring. From his stand he can follow the motions of the hooks and attend to all his levers, which are duly marked, without changing his position. The engines, gears, and attendant's stand are all in an iron cab which is fitted with windows. The tripod structure forms with its box connections, placed under the floor, an exceedingly strong and rigid system, and the loads are well distributed. The central foundation block, under the jib table, is exposed to vertical pressures only; the two others receive either vertical pressures or act as counterweights for the load.

Four or five of the diagrams have been prepared from illustrations in a valuable Paper—"Moderne Werftanlagen und ihre voraussichtliche Entwickelung" by Tjard Schwarz, published in the Jahrbuch der Schiffbautechnischen Gesellschaft 1901 (page 55), an Institution which is prospering in Germany; while the author is also indebted to several firms, including the Duisburger Maschinenbau Aktien Gesellschaft, the Brown Hoisting Machinery Co., the Wellman-Seaver Engineering Co., etc., for others of the illustrations.

Discussion.

The PRESIDENT moved a cordial vote of thanks to Mr. Dunn for his valuable Paper.

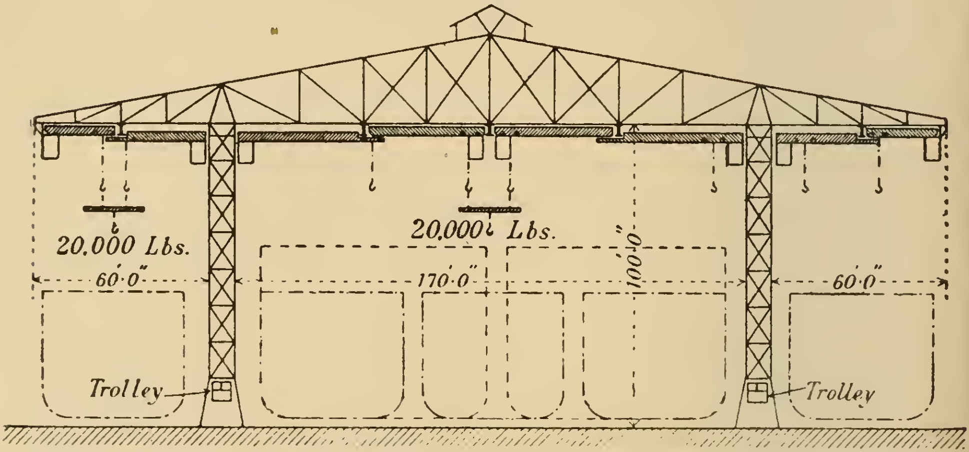
Mr. ARCHIBALD P. HEAD thought the best thanks of the Institution were due to the author for the able way in which he had dealt with a subject on which, up to the present time, there was very little literature. Special thanks were due for his suggestions as to the type of cranes which should be adopted in shipyards, a question which was now forcing itself upon the notice of shipbuilders throughout the world, in order that the capacity and productive power of shipyards might be increased. The author had described the various types of cranes in use for handling materials in many of the shipyards in Great Britain and America, but no mention was made of a shipyard in the latter country which he visited last November soon after its opening, namely the shipyard of the New York Shipbuilding Co., at Camden, near Philadelphia, which was about the most up-to-date shipyard in America. There were four berths, each served by overhead travelling electric cranes; parallel with them was a fifth crane covering a wet dock. As soon as a ship was launched, it was brought round to the wet dock, and was there fitted out with its heavy weights. Parallel with the river, and across the landward end of the five berths was a very long shop with certain annexes in which the plating and frames were prepared, and the boilers and engines were made. The shop was also provided with numerous rapid overhead electric cranes which ran parallel with the river, and at right angles to the cranes serving the berths. The runways of the latter were continued landwards so as to overlap a portion of the main shop. Consequently all the cranes were, to a certain extent, intercommunicating. A piece of material could be lifted from any part of the system of shops, transferred to any of the cranes serving the berths, and placed by them in any part of a ship under construction or in the wet dock.

(Mr. Archibald P. Head.)

The electrical installation of the works was also interesting. Two systems of electric current were available, continuous current for lighting and for motors which stopped and started frequently, or started upon a heavy load, and alternating three-phase current for those motors which were more or less regularly running. Instead of having two sets of generating apparatus, the two kinds of current were produced by the same machines, which were rotary transformers, and which gave off polyphase current on one side and continuous current on the other, the relative quantities produced being entirely automatic. If all the alternating current machinery stopped, so much more continuous current was given off, and *vice versâ*.

He would also like to mention another modern shipyard outfit in America. It was that of the Fore River Engine Works at Boston, Mass., where an installation was now being put up, Fig. 35. It had been designed and was erected by the Wellman-Seaver Engineering Company, whose system of under-lapping cranes was referred to in the Paper (page 566). It would be seen that the runways for the cranes were supported by a series of cantilever trusses spaced 60 feet apart. That great distance of spacing would, he believed, obviate the objection to the blocking out of the light urged by the author

Fig. 35. Eight 5-ton Cranes over Four Ship-Berths.
Moving Cranes crosshatched.
(Details, see Figs. 15 and 16, Plate 100.)



against the overhead system. It could be roofed over if required; owing to the severity of the climate in winter, he believed it would be roofed over in this particular case. The trusses were supported on a series of columns, spaced 170 feet apart laterally, allowing room between them for two large or three small ships, while under the overhanging cantilever portion on each side there was room for one ship of unlimited breadth. It would be seen that each ship had the exclusive use of two electric cranes of five tons capacity each, which moved very rapidly. The cranes were of the three-motor type, containing a separate motor for longitudinal travel, for cross travel and for lifting, while the operator travelling with the crane was always in full view of his work. A capacity of five tons struck one as being rather low, after hearing of the cranes of fifteen tons and upwards mentioned by the author; but it must be remembered that the vast majority of weights to be lifted in a shipyard were under five tons, while for specially heavy loads two of the cranes could be combined to lift ten tons, as shown in Fig. 35. Each pair of cranes under-lapped, so that there was no part of a ship which could not be reached by the hook of one or other of them. It was also possible to put two or more travelling cranes on one running way, so that while one was supporting the riveters, the others could be bringing plates or other material from the shops to the ship. It could not be denied that the weight of the fixed structure in this system was heavier than in the cantilever crane system, and that undoubtedly was an objection, but there was room for both systems, each having its advantages. In the system he had described, the weight of the moving crane was minimised and current thereby economised, while the fixed structure was heavier; whereas in the double cantilever crane system the weight of the fixed structure was minimised, while the weight of the moving crane was considerably heavier, necessitating an 85-H.P. motor against about a 25-H.P. motor for the longitudinal travel in the overhead-crane system.

Mr. A. TANNETT-WALKER, Member of Council, said the Institution was deeply grateful to Lieut. Dawson and Mr. Dunn for the magnificent generosity they had displayed in placing the fullest

(Mr. A. Tannett-Walker.)

information on the subjects of the Papers at the disposal of the members. He had never heard a better Paper on workshops than that of Mr. Dunn's, to whom they were indebted, together with the enterprising firm of Messrs. Vickers, Sons and Maxim, for a real treat, and he looked forward with no small amount of pleasure to the visit to the firm's works.

The author had given some descriptions of very powerful cranes. He had mentioned a big crane made in Germany for Herr Krupp, and another constructed at Düsseldorf, and he had referred (page 576) to "a splendid hydraulic crane made by Messrs. Tannett-Walker and Co." That crane was made in 1887. Whatever the Germans were doing at the present time, Englishmen were certainly ahead of them then. It lifted 160 tons and 30 tons with ranges of 70 feet and 75 feet 3 inches, and a height of jib of 125 feet with a test load of 320 tons. The roller path was 45 feet 4 inches in diameter; the foundation was 50 feet in diameter and 20 feet deep. The crane was made at Leeds for the Government workshop at Chatham. When the foundations were fixed, a steam-engine and a large bar were employed to turn the path 45 feet 4 inches in diameter on which the live rollers worked, and when the steam-engine and all its gearing were removed, and the engineer put his straight edge on the foundation he found it had sunk. The question then arose as to whether his firm should begin to build the crane, and eventually it was decided not to do so. One thousand tons of pig-iron were put on the foundation and left there for four or five months, the foundation sinking $1\frac{1}{4}$ inches. After it had sunk, the pig-iron was taken off, the erection of the crane was commenced and completed, the test load was put on and the crane passed. He thought that was a triumph of engineering skill.

The PRESIDENT thought the members would fully endorse Mr. Tannett-Walker's remarks with regard to the generosity with which details had been placed at their disposal in the Paper. The Appendix (pages 582–586) given of the power required to work various tools electrically was of very great value at the present moment when the practice of electric driving was being so largely adopted.

Mr. JAMES DUNN, in reply, thanked the President for his appreciative remarks and the members for the attention with which they had listened to his Paper.

BARROW DOCKS
AND APPROACHES BY LAND AND SEA.

By Mr. FRANK STILEMAN, of London and Barrow-in-Furness.

The Barrow Docks,* Plate 108, are owned by the Furness Railway Company, who are also the Harbour Authorities.

The railway system connects with the Midland at Wennington Junction (the line between Wennington and Carnforth being jointly owned by the Furness and Midland Railway Companies), and with the London and North Western Railway at Carnforth and Oxenholme to the South, and Whitehaven on the North. The Furness Railway Company also owns and works the branch lines to Lake Side (Windermere), and to Coniston Lake, and on both Lakes it has a regular service of steam yachts.

The following are the dates of the opening of the various lines now constituting the Furness Railway system:—

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* See also "Docks and Railway Approaches at Barrow-in-Furness," by Mr. F. C. Stileman; Proceedings 1880, page 324.

DATES OF OPENING.

Main Line.

Year.		Miles.	Chains.
1846.	Dalton to Kirkby	6	69
1847.	Roose to Barrow Old Passenger Station	1	33
1848.	Kirkby to Broughton	3	43
1849.	Ravenglass to Whitehaven	16	61
1850.	Foxfield to Ravenglass	17	45
1851.	Lindal to Dalton	1	53
1854.	Ulverston to Lindal	2	68
1857.	Carnforth to Ulverston	19	35
1867.	Millwood Junction to Dalton Junction	0	33
1873.	Barrow, Old Station, to Ormsgill Junction	1	70
1881.	St. Luke's Junction to Barrow Docks	1	42
1882.	Barrow and Park Loop (Salthouse to Park)	5	41
		79	33

Branch Lines.

1846.	Goldmire Junction to Piel Pier	6	13
1859.	Broughton to Coniston	8	67
1863.	Hawcoat Branch	0	52
1865.	Millom to Hodbarrow	1	49
1867.	Crooklands to Stainton	1	56
1869.	Levens Junction to Greenodd Junction	0	29
1869.	Ulverston to Lake Side	9	38
1873.	Salthouse Junction to Stank	1	74
1876.	Arnside to Hincaster (Kendal Branch)	5	25
1882.	Oak Lea and Goldmire Junction	0	31
1883.	Plumpton Junction to Bardsea (Priory Station)	2	00
		38	34

Joint Lines.

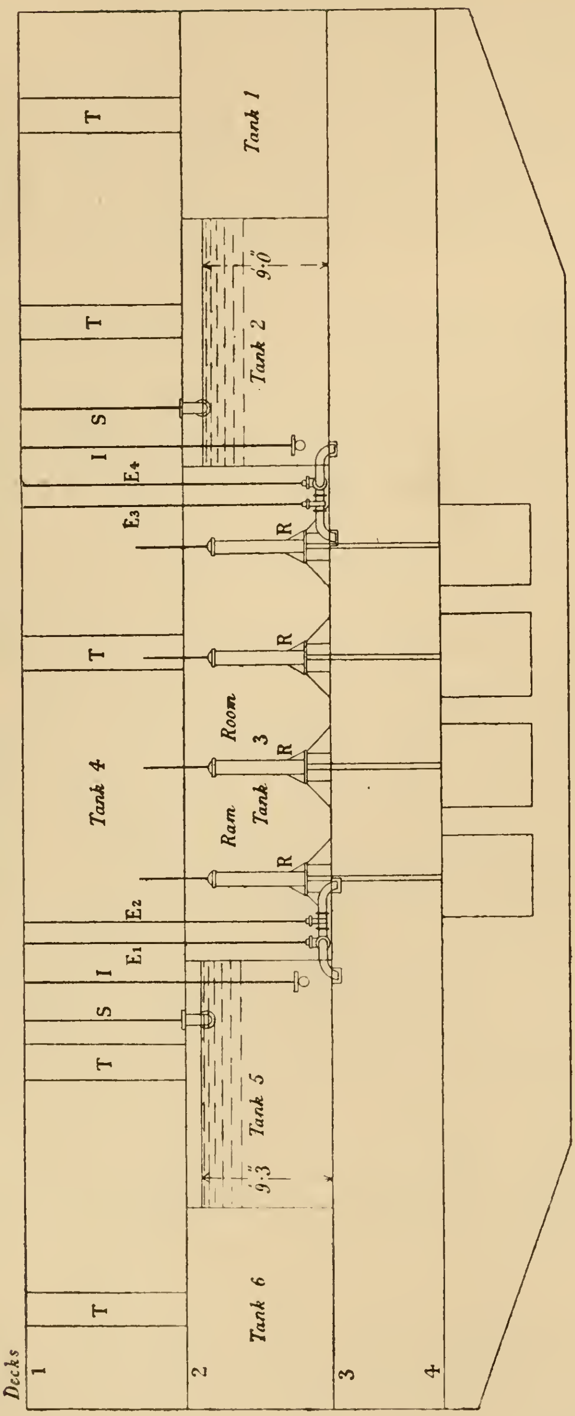
1867.	(F. and M. Joint) Carnforth to Wennington	9	50
1880.	Carnforth (F. and M. Curve)	0	21
		9	71
	Total	127	58

The approaches to the docks from the sea are past Hilpsford Buoy to the south west of Walney Island, through a dredged cut some 300 feet wide, and of a depth of 14 feet at low water ordinary spring tides, thence round the south end of Walney, past Piel and Roa Island (from which the Belfast steamers used to depart years ago), up Walney Channel and past what was once an island known as Barrow Ramsey, but now forming the southernmost end of the dock system.

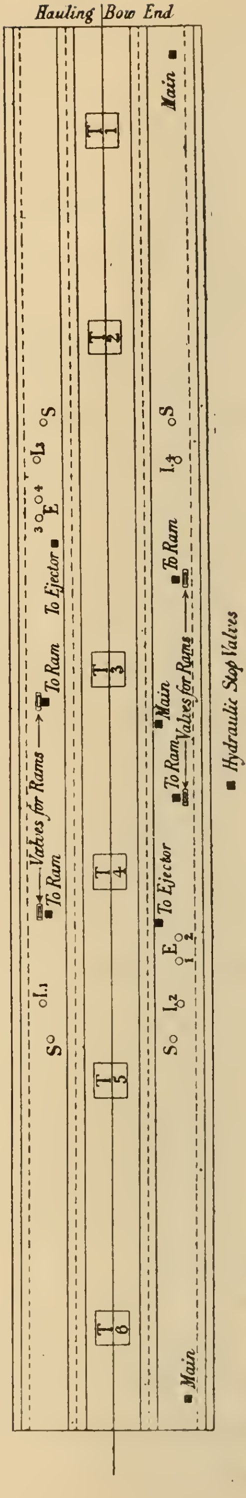
There are therefore four reaches from the sea to the Ramsden Dock entrance, all of which have required a considerable amount of dredging. Three of them are provided with six leading lights, two in each reach; the first in each reach are constructed in timber work, the back ones of brick work, the front panels of which are of white glazed bricks.

Nos. 1 and 2 reaches are also provided with illuminated buoys lasting for three months; some of them are Pintsch's gas buoys, while others are Wigham's oil buoys. These latter are now being experimented with. They consist of a copper cylinder with a receiver on top. The wick, which is carbonized and is burnt horizontally, passes over a roller on top. The burner is surmounted by a combustion cone and surrounded by lenticular apparatus; one end of the wick is conveyed up through an oil-tight copper tube with holes in its sides, and the other end is brought down through a tube standing above the level of the oil in the lamp, and soldered or secured at the lower end. A circular float is placed in a copper cylinder fixed to the bottom of the lamp and filled with oil. When the lamp is first lighted, this float is at the top of the cylinder and is attached by means of hooks or loops to the wick. The oil in the cylinder is caused to drop slowly out of it through a valve of peculiar construction supplied by a cotton core, at such speed as may be necessary.

Ramsden Dock.—The entrance to this dock is situated to the north of Barrow Ramsey, and has entrance gates 100 feet wide, with a depth of 31 feet 6 inches of water at high water ordinary spring tides.



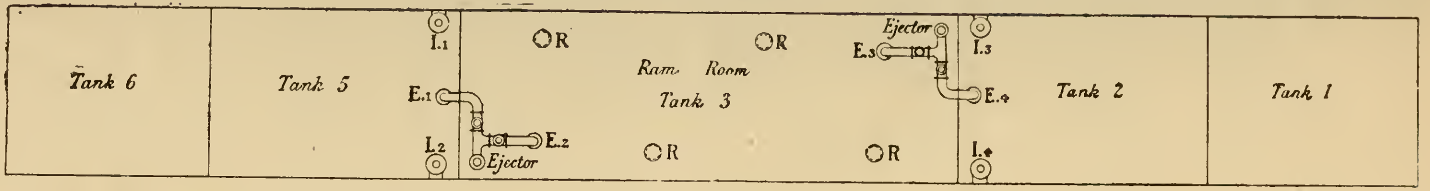
Sliding Caisson.—Arrangement of Decks, etc.



Plan of No. 1 Deck.

Scale, 18 feet to 1 inch.

Plan of No. 3 Deck.



E. Ejector Suction Valve. I. Inlet Valve. R. Ram. S. Scupper Valve. T. Trunk.

Notes.

No. 1. Ejector Suction Valve draws from No. 5 Tank. No. 2. Ejector Suction Valve draws from No. 3 Tank (Ram Room).
,, 3. ,, ,, ,, ,, ,, ,, 3 ,, (Ram Room). ,, 4. ,, ,, ,, ,, ,, ,, 2 ,,

To Flood No. 5 Tank, open Inlet Valves No. 1 and No. 2. To Flood No. 2 Tank, open Inlet Valves No. 3 and No. 4.
,, ,, ,, 3 ,, ,, either Ejector Suction Valves Nos. 1 and 2 and Inlet Valves Nos. 1 and 2.
or ,, ,, ,, Nos. 3 and 4 ,, ,, ,, Nos. 3 and 4.

Depth of Water in No. 2 Tank not to be less than 9 ft. 0 in. nor more than 9 ft. 1 in.
,, ,, ,, ,, ,, 5 ,, ,, ,, ,, ,, ,, 9 ft. 3 in. ,, ,, ,, 9 ft. 4 in.

Tanks Nos. 1, 3 (Ram Room), and 6 to be kept dry.

Scupper Valves to Tank No. 4 on Dock side of Caisson will always be left open except at high spring tides. When water in lock rises above level of water in dock, the valves on dock side must be closed and those on lock side opened, reversing them again as soon as tides fall to dock level. All sluices open by moving levers over to south side. All valves open with a left-hand motion and close with a right-hand motion. All valves except the scuppers to be kept closed.

To the north of this entrance a quay wall has been built, having a depth of water varying from 12 feet 6 inches to 20 feet at low water ordinary spring tides, fitted with hydraulic cranes, sheds, etc., and behind which is the Ramsden Dock Railway Station, from which passengers embark for Belfast and the Isle of Man, the former boats sailing nightly throughout the year, the latter sailing daily from Whitsuntide to the end of September.

The station is provided with two passenger subways, the larger one, for the Isle of Man service, having a hydraulic lift with an approach which at high water is level, at half tide assumes an incline, while at low water it is in the form of steps.

The dock entrance basin is 900 feet long, and has four berths fitted with twelve hydraulic cranes. Where the foundations have been found good at a reasonable depth, concrete walls have been constructed *in sitû*, where there are poor foundations, and at a considerable depth open timber quays have been built, the piles of which, and the under-water timbers, are of Karri wood. The gravel of which the concrete is made comes from the south end of Walney, and is of the very best description.

The lock, 100 feet in width, is fitted with two pair of gates, and a sliding caisson—the caisson having taken the place of one pair of gates, which were originally erected there previous to the cill; a portion of the invert of the lock at this point having been recently lowered 6 feet, makes it uniform with the cills at the entrance to these docks, and at the western end of the lock. The necessity for lowering this cill was due to the heavy draught of the men-of-war, cruisers, and other large vessels that have been, and are being built at the Naval Construction Works of Messrs. Vickers, Sons and Maxim. The work of lowering the cill was completed in the present year, and the appearance of the invert before and after this lowering is respectively shown in Plate 109. This lowering will permit of the railway company, when trade demands it, constructing any new quays that may be required to such a depth that they will be capable of accommodating vessels drawing 30 feet of water. The caisson, shown in diagrammatic form (pages 598–9), is tank-shaped, 103 feet long by 12 feet wide, and 39 feet 6 inches in depth. It is worked by means of chains and hauling bow actuated by small hydraulic engines, placed at the head of the caisson recess, to reduce the resistance when hauling the caisson; the bottom and lower parts of the ends have been left open, so enabling the water to flow freely through longitudinally, the water ballast can at the same time be reduced by means of hydraulic ejectors, the ejected water being readmitted when the caisson is at rest. Four sluices each 6 feet by 6 feet go through the caisson, and are opened and closed by double-acting hydraulic lifting cylinders. The sluices have been made of large dimensions in order to equalise rapidly the head of water between the lock and the dock, so enabling vessels to pass either way without loss of time.

To the north of the lock and basin is a steamer dock with quay walls 3,000 feet in length, provided on the south side with grain sheds, etc., the north side being used almost entirely for the shipment of pig-iron, rails, or the unloading of iron ore.

Petroleum Storage Tanks.—On the west side of the Ramsden Dock are two petroleum storage installations, Plate 110; the smaller one consists of two tanks with a capacity of 2,500 tons, while the other consists of six large tanks, two small ones, and a settling tank, having a total storage capacity of 16,360 tons. Large barrelling sheds and cooperage have also been provided.

The author believes this storage to have been the first erected in England, and it has been so laid out that, when the oil has been pumped from the steamer into the tanks, the remainder of the work, such as barrelling the oil or loading the oil into tank wagons, is done by gravitation. The barrels, either loaded or empty, are, when required, run on slightly elevated railways, Plate 110, either to or from the ship. These gangways are constructed of angle-irons, and notwithstanding the speed at which these barrels sometimes run, they never come off, this being due to the bilge of the barrels.

The tanks, Plates 111, 112, and 113, are constructed of wrought-iron, the bottom plates being $\frac{7}{16}$ inch thick, fitted with an angle-iron $4\frac{1}{2}$ inches by $4\frac{1}{2}$ inches by $\frac{1}{2}$ inch, and are varnished black underneath. The side plates are eight in number, their dimensions being 13 feet in length and 4 feet $1\frac{1}{2}$ inches in width, varying in thickness from $\frac{7}{16}$ths to $\frac{1}{4}$ inch. The dimensions of the top angle-irons are 3 inches by 3 inches by $\frac{3}{8}$ths. The roof, Plates 112 and 113, is conical in shape, stayed from the sides by T-irons, and its plates are $\frac{1}{8}$-inch thick. Each tank is provided with a ventilator, man-hole, and dip-hole. The bottom plates, Plate 112, are double riveted throughout, the side plates having the vertical seams double riveted, and the horizontal seams single riveted, the pitch of the rivets in all cases being 2 inches. All joints are caulked inside. There is a centre pillar in each tank composed of four angle-irons 4 inches by $4\frac{1}{2}$ inches by $\frac{1}{2}$ inch to prevent any risk of the roof settling by being overweighted by snow. The valves and discharge pipes have been provided with folding joints inside the tanks, and a light chain is fixed to the pipes to which a small buoy is attached, for the purpose of keeping the pipe above the oil to prevent any of the latter escaping in the event of the valves being left open. To lift the internal pipes, a small winch is provided outside each tank.

The author has found some difficulty in lowering tank-bottoms at other places when the dimensions have considerably exceeded the above, and has found it advantageous to erect a sand cylinder at the centre of the tanks, below the bottom, in which was erected a pole with attachments to several portions of the tank bottom. On the completion of the testing of the tank bottom the sand was gradually let out till the bottom rested on its foundations when the sand cylinder was removed through a man-hole in the bottom of the tank provided for that purpose.

Buccleuch Dock.—The passage way between the Ramsden and Buccleuch Docks is 80 feet wide, and is spanned by a railway and road bridge, which was described and illustrated in a Paper by the author's late father, Mr. F. C. Stileman, on the occasion of the last visit of the Institution to Barrow in 1880.

The north side of the Buccleuch Dock is occupied by a small timber yard, the remainder having been originally used for the loading into ships of the local iron ore, and now used for general traffic. The south side is occupied by timber yards and saw mills belonging to Messrs. Crossfield and Co.

Devonshire Dock.—The passage way between the Buccleuch and Devonshire Docks has been widened since the last visit of the Institution from 40 feet to 80 feet, and is spanned by the Michaelson High-Level Bridge, which, over the opening, is constructed as two distinct bridges, each of 29 feet in width and 200 feet in length.

These opening spans are worked independently, each being raised 3 feet 6 inches by three cylinders, the two side ones being 1 foot $5\frac{3}{4}$ inches diameter each, and the centre one 2 feet 1 inch diameter. To each group of three cylinders a cross-head on top is provided, and cast-steel rollers attached. On raising the bridge to its required height, the lifting gear is automatically locked. The bridge is then hauled back, over live rollers fixed in the main structure, by an endless chain attached to the tail end of the bridge, and worked hydraulically.

To replace the bridge a horn is provided at the nose end, which goes into a roller and lifts the bridge off the back rollers to allow the ballast-box end of the bridge to go down first, and when this end is in position, the end at the island side is lowered down.

A considerable portion of the approach to the Michaelson Bridge consists of a viaduct with a roadway 60 feet wide erected on cast-iron columns. The whole of the work from Barrow Island, over the dock passage and railways as far as the Strand, was constructed by the Furness Railway Company, and the remainder by the Corporation.

The north side of this dock is occupied by transit sheds, grain warehouses, corn mill, and jute sheds, the south by timber and contractors' yards, a depositing dock which is capable of lifting vessels 300 to 400 feet in length in thirty minutes; two gridirons have been provided in connection with the depositing dock on which vessels up to the lifting capacity of the depositing dock can be placed, so providing accommodation for three vessels, and by Messrs. Vickers, Sons and Maxim's wharf, where they engine and fit out the numerous vessels they build. The dock is connected with the Walney Channel by a tidal basin 500 feet in length, with a 60 feet entrance, whose cill is 6 feet higher than that of the Ramsden Dock. To the north of this basin is a graving dock with an entrance direct from the channel, 60 feet wide and also 500 in length.

The dock is situated rather more than a mile and a half northwards of the Ramsden Dock entrance, and a large portion of the channel frontage between these two entrances—on its eastern side—is occupied by the works and launching ways of Messrs. Vickers, Sons and Maxim, and by the dockyard belonging to the railway company, where all their floating plant is repaired.

General.—The following statement shows the areas of the docks:—

	Acres.
Ramsden Dock Basin	8
Ramsden Dock Lock	2
Ramsden Dock	60
Timber Dock (Timber Pond)	21
Buccleuch Dock	31
Devonshire Dock	31
Cavendish Dock (used as a reservoir at present)	146
Total	299

All the dock gates, caissons, bridges, cranes, etc., are worked by hydraulic power, there being two installations—one at the Ramsden Dock entrance, amd the other at the Devonshire Dock entrance.

Walney Island, which is about 10 miles in length, shelters the whole of the Barrow harbour and Piel anchorage, the latter being a harbour of refuge.

The railway company, as the harbour authority, is entitled to levy dues from Sheep Island, about a mile west of Piel Island, to the north end of Walney Island, and has jurisdiction from the entrance into the harbour at Hilpsford at the south end of Walney up the channel to somewhat seaward of the north end of Walney Island. The company has spent large sums of money in deepening and improving the channel from the sea to the docks, and in erecting leading lights on every reach of the channel, and at all turning points, putting down in some cases Pintsch's gas buoys, and in others Wigham's oil buoys. A model of the latter was exhibited at the Meeting.

The Paper is illustrated by Plates 108 to 113 and 3 Figs. in the letterpress.

Discussion.

The President thought that those members who intended taking part in the excursion to the docks would find the interest of their visit considerably enhanced if they took a copy of the author's Paper with them. He begged to propose a hearty vote of thanks to Mr. Stileman for his interesting Paper.

REVIEW OF MARINE ENGINEERING DURING THE LAST TEN YEARS.

By Mr. JAMES McKECHNIE, of Barrow-in-Furness.

The choice of the subject of this Paper is due to the fact that at the beginning of each of the three past decades a Paper has been contributed to the Institution reviewing the progress of Marine Engineering. At the Liverpool Meeting in 1872,* Mr.—now Sir—Frederick Bramwell, Bart., Past-President, gave some characteristically racy reminiscences; at the Newcastle Meeting in 1881,† Mr. Frank C. Marshall, who has done so much for the advancement of Marine Engineering, continued the records of development; and again at the Liverpool Meeting in 1891‡ a similar decennial review was made by my friend and predecessor, Mr. Alfred Blechynden, whose early death in 1897 terminated prematurely a brilliant career. A similar review is appropriate now at the beginning of a new century, when there is a general tendency to erect mile-stones marking the stages reached in each branch of science. As to the selection of author, the responsibility is the President's, and he was doubtless influenced solely by the fact that this year's Summer Meeting is being held at Barrow-in-Furness.

Fuel Economy.—As the engineer cannot ignore the dictates of finance, progress must primarily be measured from the standpoint of economy. A steamship is built to carry a given load of passengers or of material for a given distance; and success is reckoned according to the expense incurred in doing this work. The engineer's part is considerable, and is largely associated with fuel economy and repairs, as well as with first cost. It can scarcely be said that the development during the past decade has been so marked, so far as fuel economy is concerned, as that in immediately preceding decennial periods; largely, because each successive attainment necessarily involves relatively greater effort. In 1872, the coal consumption was recorded as 2·11 lbs. per unit of power per hour; by 1881 it had been brought down to 1·83 lbs.; in 1891, when the triple expansion engine had come into almost universal use, the rate became 1·52 lbs.; and now, a careful analysis shows that the average for new ships with the latest equipment is about 1·48 lbs.

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* Proceedings 1872, page 125.

† Ibid, 1881, page 449.

‡ Ibid, 1891, page 306.

TABLE 1.—*Average results of Marine Engines,* 1872, 1881, 1891, 1901.

Boilers, Engines and Coal.		Average Results.			
		1872.	1881.	1891.	1901.
Boiler Pressure	. lbs. per sq. inch	52·4	77·4	158·5	197
Heating Surface per square foot of Grate	sq. feet	—	30·4	31	38 & 43*
Heating Surface per I.H.P.	sq. feet	4·41	3·917	3·275	3·0
Coal per square foot of Grate	. lbs.	—	13·8	15	18 & 28*
Revolutions per minute .	. revs.	55·67	59·76	63·75	87
Piston Speed .	. feet per minute.	376	467	529	654
Coal per I.H.P. per hour .	. lbs.	2·11	1·83	1·52	1·48
Average Consumption on prolonged sea voyage .	. lbs.	—	2	1·75	1·55

* Natural and Forced Draught respectively.

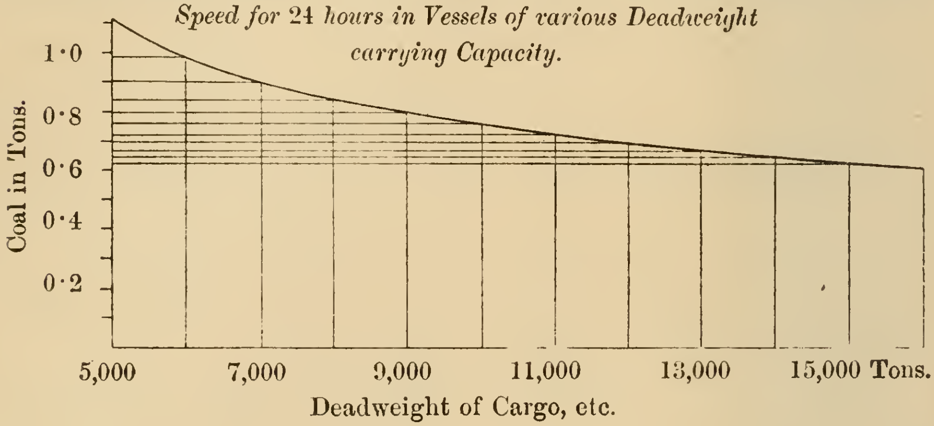
In determining coal consumption, actual performances at sea should be taken rather than trial trips results, as seems to have been the case in preceding Papers; and thus the coal consumption of 1881, instead of being 1·8, should rather be 2 lbs., or 2·1 lbs., for as shown in Table 10 (pages 650–1, lines 1 and 3), the mean consumption of twelve steamers built in 1878–80, and fitted with compound engines, on voyages aggregating 340,000 miles, works out to 2·1 lbs. per I.H.P. per hour. Again, the coal consumption of 1891 was given as 1·52 lbs.; but the sea record of ships built then show a consumption of between 1·75 and 1·8 lbs., as recorded in Table 9 (page 647), giving a comparison of performances between Liverpool and Grand Canary, voyages which occupy about a week, and represent each from 1,400 to 1,700 miles steaming. Some little allowance, however, should be made in this case for the coal used for pantry and heating purposes during the voyages. Thus it may be said that in 1881 the average consumption at sea was 2 lbs. per H.P. hour; in 1891 1·75, and now about 1·55 lbs., Table 8 (page 645). Upon the sea performance the saving today is about one-fifth of a pound per H.P. per hour as compared with ten years ago; and about ½ lb. as compared with twenty years ago—a result which is the more satisfactory when it is borne in mind that it has been attained without multiplying the working parts of the engine, or so increasing the delicacy of the machinery as to involve a higher skilled labour in its management on shipboard.

The increased economy is partly due to the higher steam-pressures now in use. In 1891 the average was about double that of 1881, and now the increase is from 158 to 197 lbs. per square inch, the average for forty-five ships with triple expansion engines built within the past nine months being 180 lbs., and for nine steamers with quadruple expansion engines 214 lbs. In former years, naval machinery was included in the reckoning, the conditions being similar to those obtaining in the Merchant Service; but now, with the adoption of water-tube boilers, the practice is dissimilar, and naval ships are not considered in determining this year's averages. As a result of the higher steam-pressure and more economical engines, more power is obtained from the boilers per square foot of heating surface, the average per I.H.P. having in ten years decreased from 3·275 to 3 square feet. At the same time the piston speeds of engines have considerably increased. The average, ten years ago, even including war-ships, has now become the mean rate for the tramp steamer—530 feet per minute, while many steamers for high speed attain to 880, a few to 950 feet.

Economy per 100 *Ton-Miles of Large Cargo Carriers.*—Improved economy in the oversea transport of commerce is also being sought for now in the greater size of cargo steamers, the fuel consumption of which does not increase in the same ratio as the cargo capacity. This point is illustrated in the diagram, Fig. 1 (below), which shows the coal consumption per twenty-four hours for each 100 tons of deadweight carried in vessels of progressive size, each steaming 13 knots. The particulars of the various ships upon whose performances this diagram has been based, are set out in Table 11 (page 652). It will be seen in the first place that the displacement of the ship itself does not increase in quite the same proportion as the deadweight carried, the immersed midship area increases at a slower rate than the load displacement, and the power necessary for a given speed advances at a correspondingly lower ratio. Thus, a ship to carry only 5,000 tons requires machinery of 3,475 I.H.P. to propel her at 13 knots; while, in the case of a ship of treble the capacity, the power is scarcely double. In other words, the consumption of coal per hundred ton-miles in a now relatively small ship taking 5,000 tons of cargo, is

FIG. 1.

Curve showing the amount of Coal required to propel 100 *tons of Cargo at* 13 *knots Speed for* 24 *hours in Vessels of various Deadweight carrying Capacity.*



8 lbs., while the vessel taking 16,000 tons uses only 4·4 lbs. per hundred-ton miles, the rate of consumption per unit of power per hour being assumed in all cases at 1·5 lbs. Not only is the fuel consumption per ton carried less, but the first cost per ton carried need not be greater, and the working expenses per ton generally are lower, because mechanical means are introduced more freely for many purposes, while the personnel does not increase pro rata with size.

This greater economy is the cause of the steady growth in the size of ships, and Table 12 (page 653), is therefore instructive as indicating the size of vessels launched in the United Kingdom in each year since 1892. It needs no comment. The total number of vessels of over 10,000 tons in existence ten years ago was two; now there are fifty-one, of which ten are over 13,000 tons. Ten years ago there were only ninety-one vessels which exceeded 5,000 tons register; at the end of last year there were 505. The distribution of these vessels in point of tonnage and of nationality is recorded on Table 13 (pages 654–5), showing that the higher economy of the larger ships is being widely recognised. Germany, it will be noticed, maintains her position with Britain so far as large ships are concerned. But these are questions of general policy; details as to the problems involved in the attainment of economy are of more importance.

Steam Pressures and Boiler Testing Standards.—The author naturally begins with steam generation, and it will no doubt conduce to the general harmony if the subject of the water-tube boiler is not dealt with. It would demand too much time; the question is more or less *sub judice*, and its consideration in any case would involve a protracted discussion, perhaps without direct value, as there are very few engineers who can boast that they have not taken out a patent for a water-tube boiler. There is enough in connection with cylindrical boilers as well as with machinery practice generally upon which a free expression of opinion is desirable. There has come within the past ten years some uniform degree of practice as regards cylindrical boilers. There is generally a preference for the single-ended type, although convenience often requires the adoption of the double-ended boiler; but the through combustion chamber has, generally speaking, become a thing of the past. It has already been pointed out that the pressure for forty-five ships fitted with triple-expansion engines within the past nine months averages 180 lbs., while in the case of nine steamers with quadruple-expansion engines it averages 214 lbs., the maximum attained with cylindrical boilers for merchant practice being 267 lbs. In the naval service steam-pressures of 300 lbs. are now quite common with water-tube boilers. There is thus an increase on the average in merchant steamers of about 25 per cent. and in naval practice of 100 per cent., as compared with ten years ago.

It would seem as if the limit was being reached with tank boilers, because in the case of the boiler to work at 267 lbs. the shell plates are $1\frac{19}{32}$ inches thick, although the diameter is only 13 feet. The boiler illustrated on Plate 114, for the s.s. "Ortona," built at the Naval Construction Works at Barrow-in-Furness, is probably as large as any yet constructed, the diameter being 17 feet, and here the shell plating is barely so thick as that of the boiler already referred to; but, on the other hand, the steam pressure is only 190 lbs. Ten years ago there was a strong desire that the Board of Trade and Lloyd's might reconsider the ratio of test pressure to the working pressure, but it still continues to be double. The Board of Trade have in special cases accepted shell plates having a tensile strength of 29 to 32 tons per square inch, but the margin here between maximum and minimum is very small, and each plate must be tested by the Surveyor. The material test required by the rules is the same as ten years ago, namely from 27 tons to 32 tons. Prior to the adoption of the water-tube boiler, the Admiralty practice was to test the boiler up to 90 lbs. over the prospective working pressure, and in this case the test pressures for the boiler illustrated on Plate 114 would be 280 lbs. instead of the Board of Trade standard of 380 lbs. Advantage could thus be secured in decreased scantlings. For instance, the shell plate under the Admiralty rule would be $1\frac{7}{16}$ inches thick, instead of $1\frac{9}{16}$ inches. The stays would also be reduced $\frac{1}{8}$th of an inch in diameter, becoming 3 inches and $3\frac{1}{4}$ inches. The scantlings of the remaining parts would remain about the same, with the exception of the furnaces which are invariably of greater thickness in the Admiralty tank boilers. The relative stresses, factors of safety and tensile strength of material are as follows:—

Stress on Steel Stays in Steam Space.

Board of Trade	9,000	lbs. at working pressure.
„	18,000	„ „ test.
Admiralty	10,400	„ „ working.
„	18,000	„ „ test.

Factor for Shells.

Board of Trade	4·5.
Admiralty	3·9.

Tensile Strength of Material.

Board of Trade 29 to 32 tons per square inch with a minimum elongation of 18 per cent. in 10 inches.

Admiralty 27 to 30 tons per square inch with a minimum elongation of 20 per cent. in 8 inches.

It will thus be seen that for a given diameter there is, with the Admiralty rule, a possible saving in weight, or alternatively the diameter within reasonable limits of prudence may be increased, regard being had to the thickness of shell plating that may be deemed practicable. At the same time, it is a matter for consideration whether the differences in the rules as to boiler scantlings enforced by Government departments and Underwriting Associations should not be carefully examined with the view of determining some uniform standard, for while in the case of the Bureau Veritas the pressure permissible for given conditions is 5 per cent. less than with Lloyd's, the United States Board of Survey permits about 20 per cent. higher pressures.

Boiler Draught and Evaporation.—Except in war vessels the closed stoke-hold system is seldom resorted to now, the preference in the Merchant Service being in favour of heating the air supply before it reaches the furnace, either by a closed ashpit forced system, as in the Howden arrangement, or with an induced draught. In both cases heat is got from the waste gases. The horse-power of ships fitted with the first mentioned heated draught system is 3,406,000 I.H.P., and there can be no doubt that very economical results have been achieved. This is the system adopted in both the Cunard ships whose results are set out in Table 8 (page 645), and it will be seen that in the later vessel, the "Saxonia," the mean consumption per I.H.P. per hour is only 1·26 lbs. during the round trans-Atlantic voyage; while in the case of the Clan Line return, Table 10 (pages 650–1), the mean of seventeen voyages made by twelve steamers is 1·39 lbs.—an eminently satisfactory result. With this system of draught it is possible to burn more coal per square foot of grate and to obtain a higher evaporation per square foot of heating surface. The average ratio of heating surface to grate area in the case of thirty forced-draught steamers built within the last nine months is 39·29. Two or three of the vessels were designed for particular trades and special fuel for which large grates are needed: but taking ordinary steamers, the ratio probably averages 42 to 43 square feet for forced draught, while with natural draught the average, also for thirty steamers, is 38·3. Ten years ago the mean for twenty-eight steamers was 31 square feet, and twenty years ago the mean of 39 steamers was 30·43 square feet; so that it will be seen that the modern cylindrical boiler has 30 per cent. more heating surface per square foot of grate. The coal burned per square foot of grate per hour in 1881 was 13·80 lbs. and in 1891 15 lbs.; it now averages with natural draught 18 lbs. and with forced draught as high as 28 lbs. Finally, the heating surface allowed per unit of power is 3 square feet as compared with 3·275 ten years ago and 3·91 twenty years ago. The increase in steam pressure and other changes has enabled the power per ton of boiler to be considerably increased, 16·5 I.H.P. per ton including fittings now being attainable in cargo steamers, 20 I.H.P. in passenger steamers, 30 I.H.P. in high speed channel steamers, and 23 I.H.P. in Atlantic liners.

Oil Fuel.—It can scarcely be said that much progress has been made in the general application of oil fuel, although it confers great advantages in uniform and easily regulated stoking. Nearly all oil-tank steamers now use liquid fuel; but few general traders have adopted the system. The disadvantage of greater cost of oil is diminishing, owing to the increasing price of coal and a more plentiful supply of oil; but apart from this, there is the slightly greater prime cost of the ship with its more carefully built bunkers to store the oil fuel. In the construction of a petroleum steamer all bulkheads require to be oil-tight, and no difficulty is therefore experienced in making the bunkers similarly tight. Even if the oil were carried in the double-bottom and water-ballast tanks, it is estimated that the care in construction and difference in structure adds £2,000 to the cost of a moderate sized ship. Oil, when water charged, involves difficulties, although separators may partly overcome these. Such objections are not insuperable, and moreover, a high degree of perfection has been attained in burner appliances; but there is still wide difference of opinion as to whether the mechanical spray, the steam or air-propelled jet or the volatilised system proves most efficient. The first requires brick lining to maintain the initial furnace temperature; the steam spray involves a loss of fresh water which has to be made up by the evaporators, and the fuel thus used is equal to from 2 to 3 cwts. per day in a 1,000 H.P. ship; with air the steam for working the compressors also involves fuel consumption, but the quantity is less than that necessary for making up the water lost by the steam spray. The boiler evaporation is probably from 12 to 15 lbs. of water from and at 212° per lb. of oil fuel, and even more is claimed in some cases. The use of volatilised oil seems to offer great advantages; it is vaporised by being first heated and subsequently distilled in the presence of superheated steam within a retort burner, and in this case the evaporation is probably slightly higher, without any initial heat expenditure of great extent. But, after all, it seems still a question of the relative price of coal and oil, so far, at least, as slow steaming is concerned. In naval practice difficulties have been experienced in securing the same amount of steam with oil fuel from water-tube boilers as is commonly obtained with coal. On a three hours' trial as much as 90 lbs. of coal has been burned per square foot of grate per hour, and it has thus far been found impossible to approach this result economically with oil fuel. In fact, the maximum power obtained with oil in the Admiralty experiments in the "Surly" with small tube boilers is less than half that obtainable with coal. When burning the oil beyond a certain rate dense volumes of smoke are formed; but with that progressive spirit which has been characteristic of the engineering branch of the service during Sir John Durston's *régime*, tests are being continued with the view of determining the best method of utilising the special advantages of the oil fuel. As an auxiliary to coal, and burned in conjunction with it, the advantages appear to be considerable; but in any case there are special risks attending its use on board warships, as the recent grounding of a German vessel demonstrated. In this case the oil fuel was liberated and caught fire, causing more damage than the actual grounding.

Mechanical Stokers.—Mechanical stokers are now widely adopted in connection with land boilers, but there are probably only two or three cases where a similar system is adopted on board ship, although there seems a wide field for them, especially if the water-tube boiler with its large grate is likely to come into favour for merchant as for naval practice, because frequent and uniform distribution of coal on the grate is necessary to complete combustion. The system fitted in one or two of the American Lake steamers for stoking water-tube boilers is of the chain type, and does not differ materially from the general run of mechanical stokers operated on land. On official trials this stoker gave satisfactory results, the consumption per hour being 33·64 lbs. of coal per square foot of grate and 1·998 lbs. per H.P. hour; while at 20·62 lbs. per square foot of grate, the rate was 1·56 lbs. per H.P. hour. At the Naval Construction Works at Barrow a stoker for marine use is at the present time being tested, but the results are not yet conclusive.

Superheating Steam.—At the moment the aim not only of the naval, but of the merchant marine, engineer, is to secure higher steam-pressures, because upon them largely depends increased economy, and at the same time there is probability of a development in the direction of the use of superheated steam. In this way, the waste heat may be further utilised in the uptake as with forced draught. Indeed, on a short trial with vessels so fitted, the steam being superheated to the extent of 57½° F., and the pressure being 267 lbs., the rate of fuel consumption worked out at 1 lb. per H.P. per hour; but a possible danger to be strictly guarded against is the multiplication of parts, especially if located in positions difficult of access when the vessel is under way. Where a premium is not given for fuel economy, or where it is not liberally divided by the ship's captain amongst the engineers, there is a probability that where the gear is in such warm corners the tendency will be to shirk periodical inspection. These remarks must be accepted in their general sense, and not as specially applied to the case in point, for credit is undoubtedly due to the promoters of this marine superheating arrangement.*

Theoretical Economy of High Steam-Pressures.—It may not be without interest to show diagramatically the theoretical advantage which may accrue from the use of high steam-pressure. In plotting the curves shown on Fig. 4 (page 618), a terminal pressure of 15 lbs. and a back pressure of 3·5 lbs. have been assumed; while the expansion is that of perfect gas (hyperbolic). The lower curve shows the percentage of gain above 100 lbs. for the mean pressure which is represented by the upper curve. Thus with steam at 100 lbs. pressure the theoretical mean pressure would be 42 lbs. per square inch; but with a pressure of 300 lbs. the mean becomes 57 lbs., so that the gain as compared with 100 lbs. steam is shown to be 35·7 per cent. It will be observed that the gain does not increase in the same ratio as the pressure.

Generally it seems doubtful whether a great advantage can accrue from the use of quadruple compounding until the initial pressure is at least 220 lbs.; and thus it comes that the practice of adopting four-stage expansion has not developed to the same extent as was anticipated ten years ago. Of the new steamers added to

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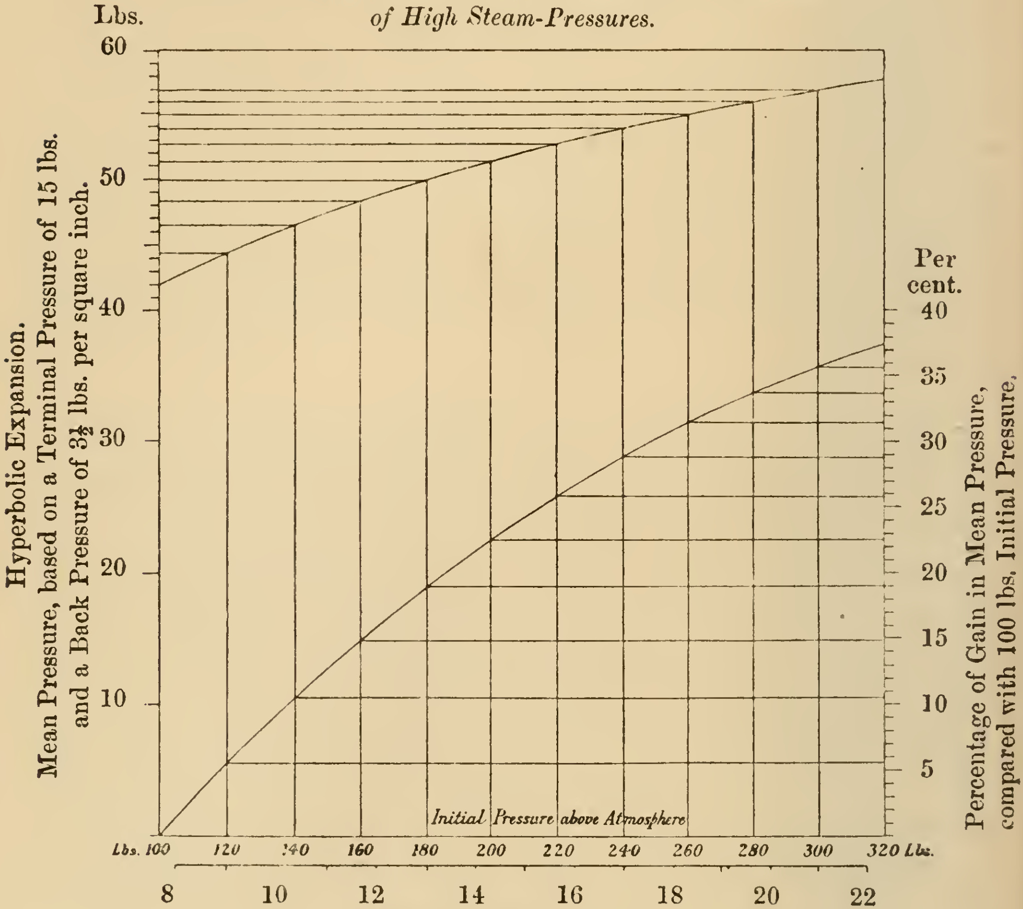
* It was fully illustrated in Engineering, 1901, vol. lxxi, page 71.

Lloyd's Register during the past nine months, only some 3 per cent. are fitted with quadruple expansion engines, and it can scarcely be said that this is due to reluctance to multiply working parts, because the practice of adopting four cylinders and four cranks for three-stage expansion has become very general in passenger steamers, even with pressures of 200 lbs.

FIG. 4.—*Diagram illustrating the Theoretical Economy of High Steam-Pressures.*



Some Difficulties of High Steam-Pressures—Pipe Joints and Flanges.—Before entering upon the question of cylinder arrangement, attention may be directed to some of the difficulties which have arisen owing to the use of high steam-pressure, especially in connection with the joints for steam and feed pipes—difficulties which have been overcome in naval ships, and which should therefore be studied by those engaged in merchant practice. In the first place, the higher steam-pressure has necessitated several changes in the material used. Solid drawn and lap-welded steel tubes are now used in place of copper pipes, and for large valve-boxes and bends gunmetal is sometimes used; but cast steel would be used more extensively, if castings as thin as considerations of strength would determine could be produced by steel makers. The full use of this material is retarded by the apparent inability to produce sound thin castings.

In the earlier warships, with high steam-pressure machinery (260 lbs.) all the steam pipes over 3 inches in diameter are of steel: in the later vessels with 300 lbs. pressures, the same material is used for all pipes over 1½ inches diameter. Such steel pipes up to 6 inches in diameter are solid drawn with weldless steel flanges screwed on, while those over this size are lap welded with a butt strap covering the weld, the flange being carefully riveted on. It was found possible to bend the steel pipes up to 4 inches, and it is to be hoped that progress will be made in this direction so as to reduce the number of expansion boxes. The higher pressures also involved change in connection with joints; and many experiments have been made. The diagrams (page 620) illustrate some types as applied in successive cruisers. Fig. 5 shows the steel flanges fitted to the steel steam-pipes of H.M.S. "Powerful." In this example the surfaces are only machine finished, the actual joint being made by a soft copper ring of triangular cross section. This system gave very satisfactory results under water test, but a few months' actual use brought about such pitting of the steel faces, due to galvanic action, that the joints would no longer keep tight. Another objection to the system was the dropping of the ring owing to its loosening as a consequence of the expansion and contraction of the line of pipe, and its being thus free to take a position eccentric to, and crossing the edges of, the bore. To overcome this the rings shown in Fig. 6 were substituted in H.M.S. "Amphitrite," in conjunction with a recess formed in each flange, to prevent the ring dropping too far

Joints for H.P. Steam and Feed Pipes. Scale ¼th.

FIG. 5.
H.M.S. "POWERFUL."

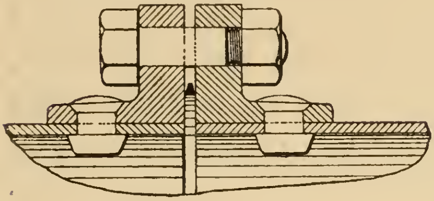
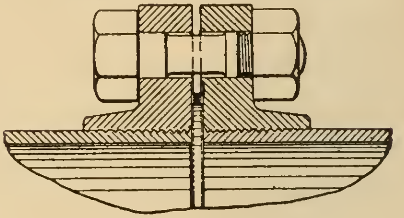


FIG. 6.
H.M.S. "AMPHITRITE."



H.M.S. "KING ALFRED."

FIG. 7.

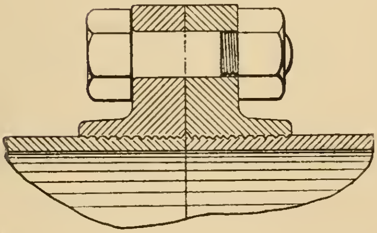


FIG. 8.

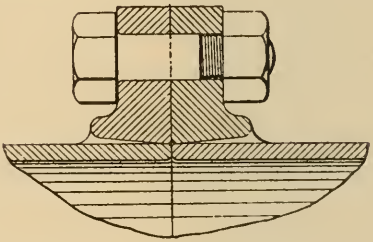
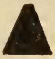
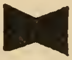


FIG. 9.—*Sections of Copper Joint Rings. Full size.*

Section No. 1.

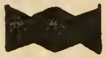


" " 2.



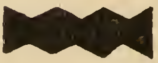
For rings up to 12 inches diameter (outside).

" " 3.



For rings above 12 " " "
and up to 20 " " "

" " 4.



For rings above 20 " " "

out of place. This effected some improvement, but the trouble from corrosion unavoidable with copper and steel in contact led to the system being discarded in favour of the form shown in Figs. 7 and 8. Fig. 7 shows a steel pipe-joint with steel flanges, Fig. 8 a copper pipe-joint with brazen metal flanges. Both are finished by hand-scraping, and the only material on the joint is a thin wash or paint of red lead and oil. This system has been adopted throughout H.M.S. "King Alfred," now building at Barrow-in-Furness. The author is of opinion that a simpler, cheaper, and efficient form of joint could be used in place of the hand-scraped flanges, namely, a joint made with asbestos paper (about the thickness of brown paper) soaked in oil, the faces of the flanges being only machined, with no scraping. Indeed this material was adopted in several instances in the feed discharge pipes in which the pressure is over 600 lbs. per square inch, the joints requiring to be re-made at sea. The results of some other tests that have come under the notice of the author are given in the list appended. They include both steel pipes and gunmetal castings, as indicated.

Arrangement of Engine Cylinders.—It may be said that so far as high-speed machinery is concerned, the universal practice is to fit a four-crank engine operated from four cylinders, usually on the three-stage compound system, and occasionally for quadruple expansion, the cylinders being arranged on the Yarrow-Schlick-Tweedy system. Ten years ago the greatest power developed in any steamer was 20,000 I.H.P., and the highest speed on an over-sea voyage 20·7 knots. Now, 30,000 I.H.P. is the highest in naval practice, the speed being 23 knots, while in merchant practice nearly 39,000 I.H.P., has been developed, the mean speed on a trans-Atlantic passage being 23·51 knots, while at the present time there is building a steamer to excel this splendid result. Full credit for this remarkable speed should be given to the company who built the vessel, the Stettiner Maschinenbau Actien-Gesellschaft "Vulcan" of Stettin, who have built for German owners the two fastest merchant vessels afloat, and are now building two to be a least equal in speed.

TABLE 2.—EXPERIMENTAL TEST OF JOINTS.

Steel Pipes and Steel Flanges.

	Description.	Remarks.	Results.
A.	Spirally corrugated spigots.	The spiral corrugations are produced by automatic cross-feed in a lathe. Eighteen threads per inch of diameter of face. Both spirals are right-handed, so that they do not fit into each other. Spigot 6⅜ inches inside diameter.	Flanges bolted together and tested by hydraulic pressures:— A commenced to leak at 2,300 lbs. per square inch. B quite tight at 2,800 lbs. (no higher pressure available).
B.	Concentrically corrugated spigot.	Corrugations formed by a chaser, sixteen per inch, those of a pair of flanges dropping into one another. Diameter of spigot = 6⅜ inches.	
C.	Cambered faces.	Machined faces only; finishing cut light, and with very fine feed. About 0·001 inch camber on each flange.	C D E all tight at 300 lbs. steam, subsequently tested under hydraulic pressure:— C commenced to leak at 2,100 lbs. D " " 1,850 " E " " 2,200 " C remade with 80-mesh gauze and red lead was tight at 2,500 lbs.
D.	Roughed.	Flanges surfaced and roughed with a file.	
E.	Flat, machined.	Same as C, but no camber. A, B, C, D all made with thin red lead and oil. E with 80-mesh wire gauze and red lead.	
		Gun Metal Castings.	
F.	Corrugated.	One flange corrugated concentrically ¼-inch pitch to within ⅜ inch of bore of pipe, the other flanges of pair plain.	All tight under 300 lbs. steam pressure. Under water test:— F leaked slightly at 1,700 lbs. G " " 2,100 " When remade all commenced to leak at 2,200 lbs.
G.	Grooved.	Slight concentric grooves on flange ⅛ inch pitch, other flange plain with slight camber. F and G made with thin paint of red lead and oil.	

The low-pressure cylinder was only occasionally divided ten years ago, and the greatest diameter was 113 inches. In the case of the "Campania" such a division was made, and although the power was nearly 50 per cent. greater than in the ship with the 113 inches low-pressure cylinders, the diameter of the largest cylinders was only 98 inches. Experience has shown the enormous importance of balancing forces in the reducing of vibration, so that there has been a further encouragement to divide the third stage or fourth stage cylinders: always provided that tandem cylinders are arranged in couples to balance each other. In this way, even although the power has reached in one set of engines 18,000 I.H.P., the largest cylinder is only 106·3 inches against the 113 inches in the 10,000 I.H.P. engine of ten years ago; the relative steam-pressures being 220 lbs. and 150 lbs. Larger diameters are not desirable, but there is no reason why with higher steam-pressure a larger number of expansions should not be adopted with multiple cylinders, because any increase in the number of cranks tends to decrease the vibration. Multiple cranks with reciprocating weights can be so arranged as to minimise the disturbing forces, and the result in the case of the "Deutschland," in which the author recently crossed to America, is that the vertical vibration measured at the extremities of the 684-foot ship was only $\frac{3}{16}$ inch.

Cylinder Ratios.—With increased steam-pressure there has come a general increase in the average ratio of low-pressure to high-pressure cylinders. Ten years ago, when the steam-pressure was about 158 lbs., the average ratios for twenty-eight triple expansion engines were as follows:—

$\frac{\text{L.P.}}{\text{H.P.}}$	$\frac{\text{I.P.}}{\text{H.P.}}$	$\frac{\text{L.P.}}{\text{I.P.}}$
6·77	2·56	2·64

With an average working pressure of 180 lbs., the mean ratios for forty-five triple expansion engines built within the past nine months are:—

$\frac{\text{L.P.}}{\text{H.P.}}$	$\frac{\text{I.P.}}{\text{H.P.}}$	$\frac{\text{L.P.}}{\text{I.P.}}$
7·55	2·74	2·76

Arrangement of Cylinders.

(For diameters, etc., see Tables 14 *and* 15, *pages* 656–661.)

FIG. 10.

"CAMPANIA" (1893).

30,000 I.H.P.

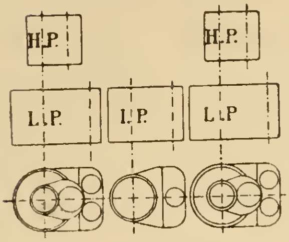


FIG. 11.

"KAISER WILHELM DER GROSSE" (1898). 28,000 I.H.P.

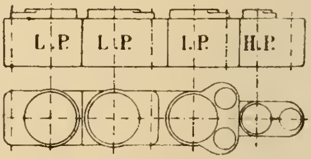


FIG. 12.

"DEUTSCHLAND" (1900).

35,000 I.H.P.

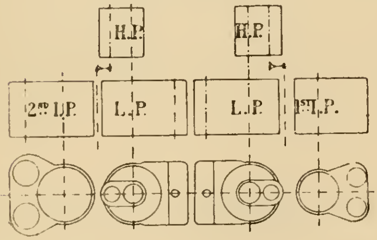


FIG. 13.

H.M.S. "KING ALFRED" (1901).

30,000 I.H.P.

(See Plates 123 *to* 126.)

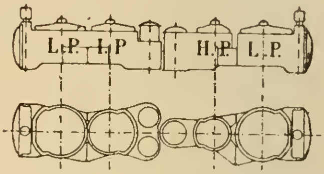


FIG. 14.

"KRONPRINZ WILHELM" (1901).

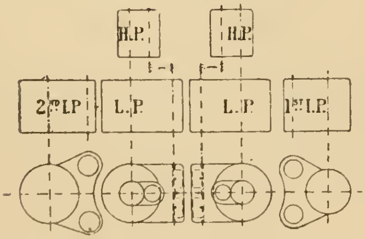
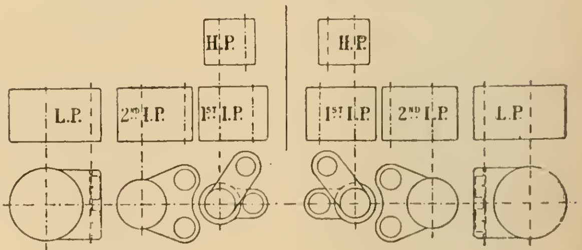


FIG. 15.

"KAISER WILHELM II." (1902).



There is some variation in practice in the ratios of L.P. over H.P., but the great majority of the cases are within one decimal point of the average—7·55, but in the case of the other two cylinder ratios the variations from general practice are more marked. Generally in fast passenger steamers for the Channel service, where the runs are comparatively short, the conditions approximate to those in torpedo-boat destroyers, where reduction of weight is more desired than economy of fuel. And thus in the Channel steamers, with from 160 lbs. to 180 lbs. boiler pressure the ratio of L.P. over H.P. is from 5·25 to 5·93. In steamers where coal economy is of importance, as is the case with large passenger liners and cargo boats generally, higher pressures have hardly brought proportionate change in ratio, the view accepted being that a large ratio of expansion is not necessary, or even helpful to propulsive efficiency, when everything is considered from fire bars to propeller. With triple expansion engines for cruisers there has been an increase consequent on higher steam pressure. In the earlier high-pressure cruisers using 210 lbs. steam, the ratio of L.P. to H.P. was 5·66, whereas with the 155 lbs. steam in former ships with cylindrical boilers the ratio was 5. In later ships, with 250 lbs. pressure, it has been increased to 7·1. Turning to quadruple expansion engines, the ratio of L.P. to H.P. ranges higher than in the case of merchant steamers with triple expansion engines using the same steam pressure. In the case of twenty quadruple expansion engines built recently the ratios are:—

$\frac{\text{L.P.}}{\text{H.P.}}$	$\frac{\text{2nd I.P.}}{\text{H.P.}}$	$\frac{\text{1st I.P.}}{\text{H.P.}}$
10·25	4·40	1·96

It certainly would be useful to have an authoritative series of tests on this question, and on its bearing upon economy, but it is difficult, if not impossible, in ordinary sea working to approximate the same conditions in several similar ships, eliminating other variants in order to arrive at a definite conclusion on one such element. Data, however, might be collated say from some of the fair-sized experimental engines in college laboratories, a notable one being that in the Durham University College of Science at Newcastle-on-Tyne. Such results as have been published regarding its experimental working* seem to show that for both triple and quadruple engines the total number of expansions may be kept comparatively low for true useful horse-power efficiency, that consequently the cylinder ratios may be kept small, and that the late cut-offs and consequent drops in receiver pressure so produced can be definitely determined to be of such value as to give the maximum economy, not necessarily on the basis of steam consumption per I.H.P., but rather on the steam consumption per effective H.P. per hour. In marine-engine research the excellent series of trials, carried out by the Research Committee of the Institution of Mechanical Engineers from 1889 to 1894, is rightly regarded as a standard for reference and guidance for future experiments.

Steam Jackets of Cylinders.—With higher steam-pressures and particularly with superheated steam, the necessity for steam-jacketing in the high-pressure cylinders at least is not so great; but there are few cases in first-class practice where the jackets are not so fitted, although generally in ordinary marine practice liners are fitted in the cylinders to ensure a hard close-grained rubbing surface, but very often steam is dispensed with in the jackets. Recent trials with H.M.S. "Argonaut"† showed that better results were got without using steam in the jackets, and the same result was shown in some more recent trials with the machinery of H.M.S. "Hyacinth" made under the supervision of the Water Tube Boiler Committee. In the slow running engines of the Merchant Service, having an early cut-off, jackets are still found to be beneficial, but only to a limited extent, and there can be no doubt that as pressures increase the use of steam in jackets will be dispensed with.

Slide-Valve Relief-Rings.—The changes which experience with higher steam-pressures have necessitated in the design of slide-valve relief-rings for intermediate and low-pressure cylinders are shown on Figs. 16 to 23 (page 627), the rings being illustrated as mounted in the slide-valve casing doors. Figs. 16 to 18

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* See North-East Coast Institution of Engineers and Shipbuilders, Proceedings 1896–97–98 and 1900.

† Transactions of the Institution of Naval Architects, vol. xli, page 1.

Relief Rings for I.P. and L.P. Slide-Valves.

FIG. 16.

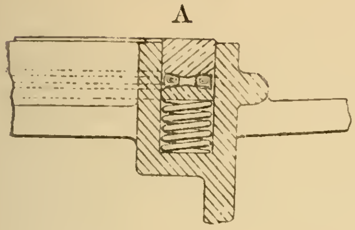


FIG. 17.

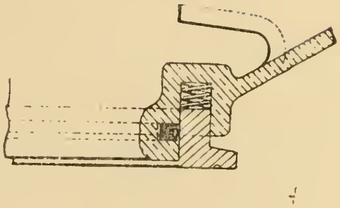


FIG. 18.

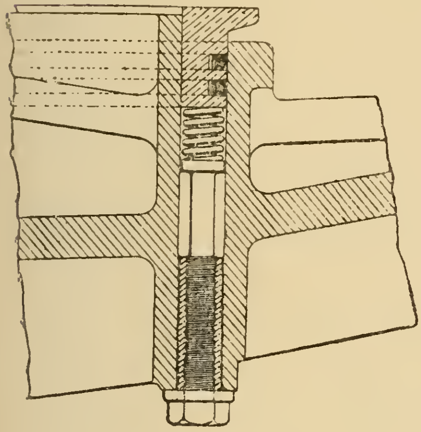


FIG. 19.

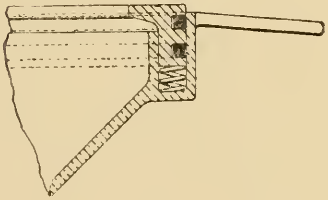


FIG. 20.

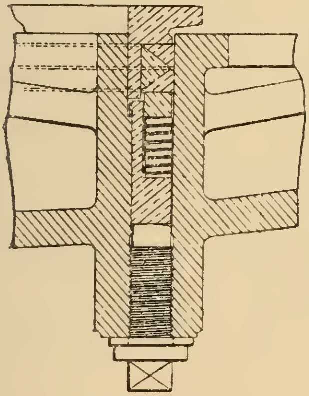


FIG. 21.

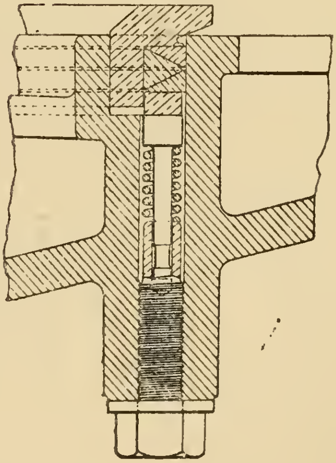


FIG. 22.

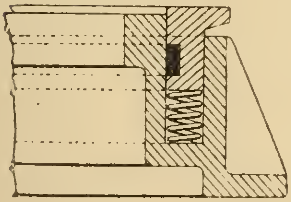
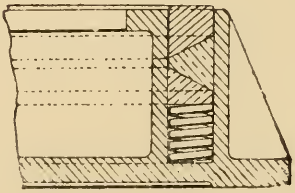


FIG. 23.



represent rings as fitted for the I.P. and L.P. slide-valves of naval engines with a steam pressure of 155 lbs. per square inch, as was usual prior to the adoption of the water-tube boiler. In Fig. 16 the ring A which bears on the back of the slide-valve is of bronze, and steam is prevented from passing around the back of it by the two rings of rubber-centred asbestos packing shown behind it, and kept pressed against the walls of the recess by the springs acting through the bevelled rings. In Fig. 17 a Ramsbottom ring is substituted for the asbestos rings. Fig. 18 is packed by Ramsbottom rings, but an improvement is effected on the system shown in Fig. 17 by the application of tap-bolts forming an adjustable abutment for the springs. This enables the pressure of the ring against the valve and of the valve against the face to be varied. In Fig. 19, which is an arrangement fitted to an engine working with steam at an inital pressure of 220 lbs., this adjustment was not fitted, although the example is more recent than to Fig. 18, but the engines to which they were supplied were of very light type.

Figs. 20 and 21 illustrate the arrangement in use in the engines of naval vessels where the boiler pressure is 300 lbs. The former, Fig. 20, is an early example of the Vickers ring system which has given very satisfactory results. In this case steam is prevented from passing by metallic packing rings of wedge-shaped sections. The load is adjustable by tap-bolts and washers as in Fig. 18, but the addition is made of a stop to prevent the valve from lifting off its face more than will allow any accumulated water to be safely forced out of the cylinder. Fig. 21 is a later and improved form developed from Fig. 20. The earlier design, Fig. 20, suffered through having to be made to suit the casing covers. In the later arrangement the cover was designed to suit the rings, and thus a better form of ring was made possible. The tail of the spring-pad piece is clear of the bottom of the hole in the end of the adjusting tap bolts, so that the valve can lift from its face as in the other examples, the amount of lift being limited to any desired amount by other long tap-bolts fitted at certain points on the same pitch circle as the spring adjusting bolts.

Figs. 22 and 23 are examples from recent mercantile marine-engines working with steam of an initial pressure of 200 and 175 lbs. per square inch. The later of these two arrangements embodies the metallic packing devices used in recent naval practice.

Piston Speed.—Reference has already been made to the increase in piston speeds; in the case of fast ocean-going steamers, as well as in naval ships, there has been a marked increase. The following Table gives the speeds for the various types:—

TABLE 3.

	Piston speed per minute.	Stroke.
	feet.	ft. ins.
Ocean-going passenger-steamers of high speed	950	5 6
Intermediate ocean-going steamers	750	4 6
Cargo-steamers	530	4 0
High-speed cross-channel steamers	880	2 9

High piston-speeds necessitate more attention being given to the lubrication of all working parts, especially of the crank-pin and main bearing brasses. Advantage has been found to accrue from the grooving of the bottoms as well as the tops of all crank-pin main bearing and crosshead brasses, as it ensures free circulation of the lubricating oil. It can scarcely be said that a large proportion of recent accidents or breakdowns have been due to high speed of rotation, care in selection of the materials of construction and in the design of working parts having reduced to a minimum the chances of failure, while at the same time, inspiring those in charge of machinery with increasing confidence.

The Diameter and Strength of Shafting.—There have been frequent failures of tail end shafts, which have led the various registries to modify their rules in the direction of a greater margin of safety, while special recommendations have been made to prevent corrosion in the stern tube; but it may suffice to give a Table showing the increase in size of shafts required by the various registries. The sizes are worked out for a three-crank vertical triple-expansion engine having cylinders 23 inches, 38 inches and 63 inches diameter with a stroke of 45 inches, the working steam pressure being 180 lbs. per square inch.

TABLE 4.—*Comparative Diameters of Shafting for an Engine of the same Power in* 1890 *and* 1900 *by various Authorities.*

	Crank Shaft.		Thrust.		Tunnel.		Propeller.	
	1890.	1900.	1890.	1900.	1890.	1900.	1890.	1900.
	ins. diam.	ins. diam.	ins. diam.	ins. diam.	ins. diam.	ins. diam.	ins. diam.	ins. diam.
Lloyd's . . .	$11\frac{3}{4}$	$12\frac{3}{8}$	$11\frac{3}{4}$	$12\frac{3}{8}$	$11\frac{1}{4}$	$11\frac{3}{4}$	$11\frac{3}{4}$	13
Board of Trade .	$11\frac{7}{8}$	$11\frac{7}{8}$	$11\frac{7}{8}$	$11\frac{7}{8}$	$11\frac{1}{4}$	$11\frac{1}{4}$	$11\frac{7}{8}$	$12\frac{1}{2}$
British Corporation	$11\frac{3}{4}$	$12\frac{3}{8}$	$11\frac{3}{4}$	$12\frac{3}{8}$	$11\frac{1}{4}$	$11\frac{3}{4}$	$12\frac{3}{8}$	$12\frac{3}{4}$
Bureau Veritas .	$12\frac{1}{8}$	$12\frac{1}{2}$	$12\frac{1}{8}$	$12\frac{1}{2}$	$11\frac{7}{8}$	12	$12\frac{1}{8}$	$14\frac{1}{8}$

The percentages of increase in the strength of the above shafts made to existing rules as compared with the rules dated 1890 are as follows:—

TABLE 5.

	Crank Shaft.	Thrust Shaft.	Tunnel Shaft.	Propeller Shaft.
	per cent.	per cent.	per cent.	per cent.
Lloyd's . .	17	17	14	36
Board of Trade	0	0	0	16·5
British Corporation	17·5	17·5	14	9

Stresses upon Materials in Cargo Steamers' versus *Torpedo-Boat Destroyers' Engines.*—While dealing with the subject of the strength of materials it may not be without interest to indicate the extremes met with in modern marine engineering practice, as exemplified by the case of modern cargo-steamers' engines and the propelling machinery of a 30-knot torpedo-boat destroyer. On Plate 115 there is given a contrast diagram (drawn to the same scale) of engines for each vessel, and Table 6 (below) shows the stress in lbs. per square inch on various parts of the two engines. From this it may be seen that the stress in the case of the destroyer is almost double so far as the crank shaft and piston-rod are concerned. A destroyer is an instrument of warfare where everything is subservient to the one dominant desideratum—high speed, and the risks run in a naval fight will not be associated only with the machinery.

TABLE 6.—*Stress in lbs. per square inch on various parts of main engines for Cargo Vessel and Torpedo Boat Destroyer.*

	Cargo Steamer. 3,750 I.H.P. 80 Revs. 7,500 I.H.P. Combined.	T. B. Destroyer. 3,000 I.H.P. 390 Revs. 6,000 I.H.P. Combined.
	Lbs. per sq. in.	Lbs. per sq. in.
Crank Shaft	3,200	6,700
Piston-Rod Body (Tensile) . . .	2,370	5,275
Connecting-Rod Bolts, bottom end . .	5,200	8,875
Piston-Rod Screw	4,150	9,150
H.P. Cyl. Barrel at Test Pressure . .	4,175	4,400
I.P. Cyl. Barrel at Test Pressure . .	3,230	4,700
L.P. Cyl. Barrel at Test Pressure . .	2,580	2,230
Factor of Safety Connecting-Rod Bolts .	12	7·575
,, ,, Piston-Rod Body . .	26·4	12·75
,, ,, Piston-Rod Screw .	13·2	7·35
Minimum Tensile Strength, Steel . .	28 tons	30 tons
,, ,, ,, , Cast-Iron .	8 ,,	9 ,,

Typical Engines Illustrative of General Practice.—On Plates 116 to 126 there are reproduced drawings of various types of engines to illustrate the general practice so far as the arrangement of cylinders, valves, working parts, and framing are concerned. Two steamers successively built for the service of the L. and Y. and L. & N. W. R. Cos. between Fleetwood and Belfast serve to show in what direction changes have been made in channel-steamer practice. The "Duke of Lancaster" was built in 1894 and the "Duke of Cornwall" in 1898. They are practically identical ships, and the engines of the former are illustrated on Plates 116 and 117, and the engines of the latter on Plates 118 and 119. It was stipulated that there should be a large reserve of power in order that a voyage ordinarily completed in $6\frac{1}{2}$ hours might be accelerated to $5\frac{1}{2}$ hours to "catch the tide." Both have twin screws. The earlier boat was fitted with three crank triple expansion engines, $\frac{24'' - 36'' - 55''}{33''} \times 160$ lbs., developing 5,400 I.H.P. at 150 revolutions. The later boat has four crank triple expansion engines, $\frac{22\frac{1}{2}'' - 34'' - 38\frac{1}{2}'' - 38\frac{1}{2}''}{33''} \times 180$ lbs., indicating about 5,700 I.H.P. at 160 revolutions. The rise in boiler pressure will be noticed, and the increase in revolutions and consequently of piston speed. The later engine is arranged on the Yarrow-Schlick-Tweedy balancing system.

A similar comparison between two cargo steamers may be suggested by reference to the S.S. "Volta," completed in 1892, and S.S. "Sokoto," constructed quite recently; both are for the same owners, and work in the same trade, and the engines of the "Sokoto" are illustrated on Plate 120. The "Volta" has single screw, triple expansion engines, $\frac{23'' - 38'' - 61''}{42''} \times 160$ lbs., the power being 1,400 I.H.P. at 70 revolutions, the specified piston speed being 500 feet per minute. The "Sokoto's" engines are $\frac{23'' - 38'' - 63''}{45''} \times 180$ lbs. single screw, the power being 1,800 I.H.P. at 85 revolutions, the piston speed thus equalling 650 feet per minute. The only other notable changes are the addition of a feed-heater to the later boat, and the substitution of a propeller having cast-steel boss and bronze blades for the cast-iron propeller used in the earlier ship.

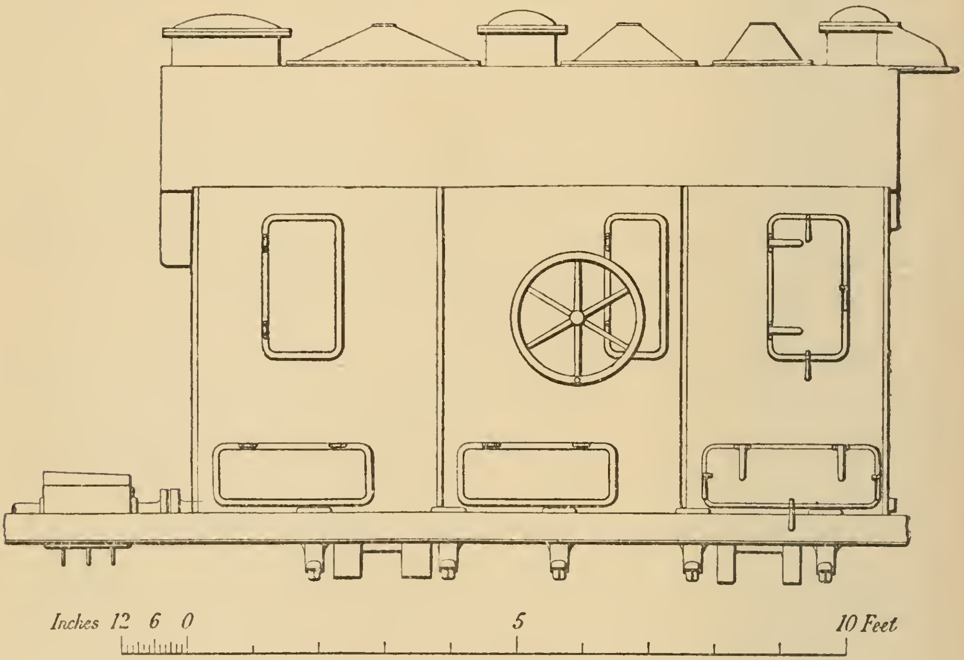
The twin-screw steamer "Ortona," built in 1898 for the Pacific Steam Navigation Company, may be considered as an example of present day shipbuilding and marine engineering, as she is intended to maintain an all-round fairly high ocean speed on one of the longest voyages in the world, carrying a good paying cargo (proportionally much greater than that carried by fast Atlantic liners) in addition to a large number of passengers of all classes. Such considerations as these put a limit on the speed at which voyages may be economically made. The cylinders of the "Ortona's" engines, Plates 121 and 122, are 30 inches, 50 inches, 83 inches diameter, by 54 inches stroke, and on trial the mean I.H.P. was 8,550 I.H.P. at 81·9 revolutions.

The engines of the "King Alfred" are illustrated as typical of naval practice today, Plates 123 to 126, and the dimensions are given fully with those of other ships on Tables 14 and 15 (pages 656 to 661). A reference to Plates 66 and 67 of Mr. Blechynden's Paper ten years ago will show the great changes made in naval engines.

Enclosed Engines.—The high speed of rotation of the destroyers' engines, which run up to 420 revolutions per minute, may make it almost a necessity to adopt the closed-in system in combination with forced lubrication. The advantage of this will be appreciated when it is stated that the space between the twin sets of engines in most of the destroyers does not exceed 3½ feet, the starting platforms being as a rule at the forward end. On Fig. 39 (page 634) there is a drawing of one of Yarrow's closed-in engines, and by way of contrast there is reproduced in Figs. 40 and 41 (page 635) the front and end elevations of an engine of corresponding type but open, also illustrating a system of forced lubrication for destroyers' engines. Any doubt entertained as to the practicability of carrying out the system in destroyers of 30 knots speed has been dissipated by the success of one of the British boats, which is working satisfactorily with closed engines and forced lubrication. The new arrangement, however, calls for a greater faith on the part of the engineer in charge, who is not able to see at all times the condition of nuts and pins. But as the whole subject has already been discussed at this Institution in a Paper read in July 1897 * by Mr. Alfred Morcom on High-Speed Self-Lubricating Steam-Engines, it is not necessary here to do further than indicate progress.

Auxiliary Machinery : Piston Packings.—The increase in steam pressures has involved several problems in connection with the auxiliary machinery on board ship. In some of the early high-pressure naval machinery there was considerable leakage in the auxiliary as well as main engines through piston and slide-rod glands having asbestos packing. In one case a packing was substituted consisting of powdered white metal, black lead and mineral grease mixed together, and held in position in the glands or stuffing-box by vulcanite rings inserted at top and bottom. It proved efficient, and even in the case of some of the main engine glands this same packing was

FIG. 39. *Elevation of Enclosed Torpedo-Boat Engines.*
(Yarrow, Poplar.)



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* Proceedings 1897, page 316.

Arrangement of Forced Lubrication, and of Cased-in Cranks and Connecting-Rods, for Twin Screw Torpedo-Boat Destroyers, 6,000 I.H.P.

FIG. 40.

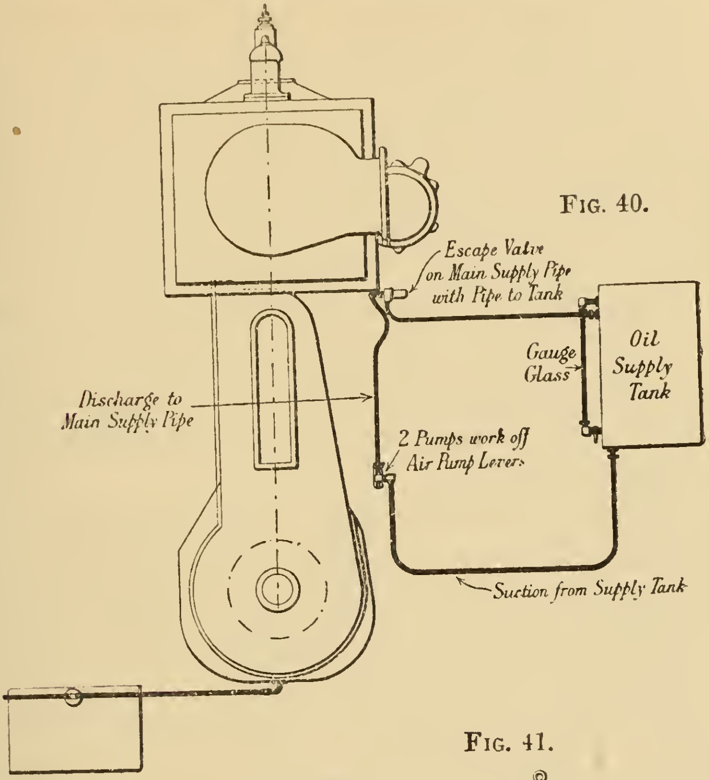
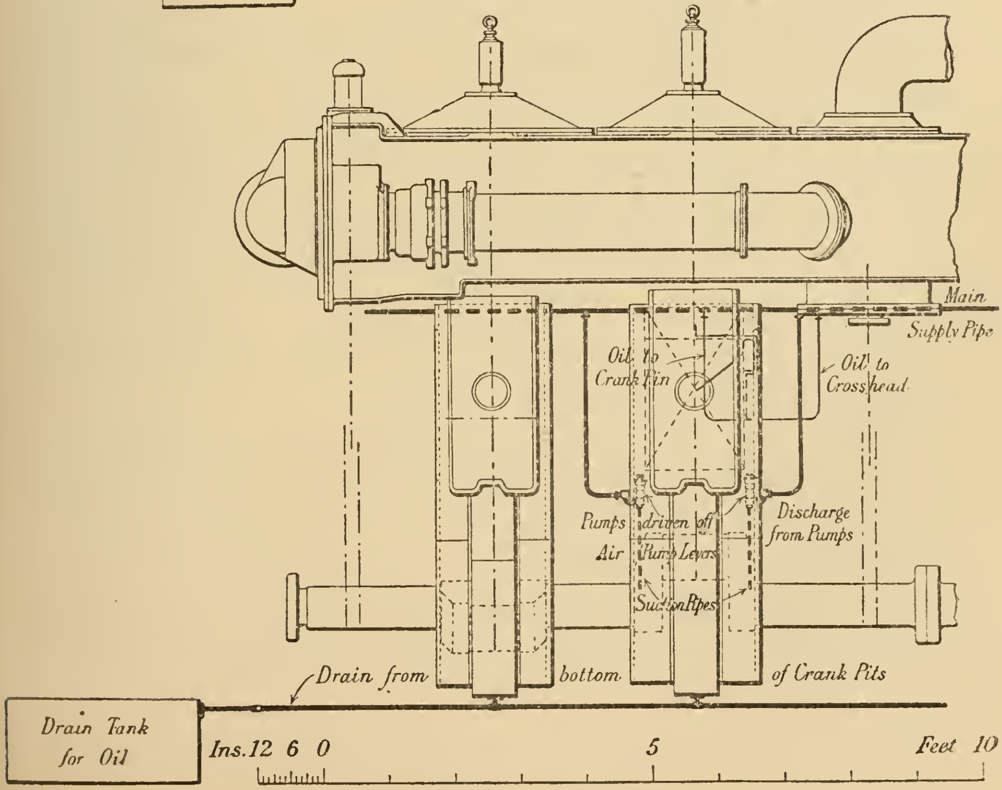

Escape Valve on Main Supply Pipe with Pipe to Tank
Oil Supply Tank
Gauge Glass
Discharge to Main Supply Pipe
2 Pumps work off Air Pump Levers
Suction from Supply Tank

FIG. 41.



substituted for asbestos, the ordinary metallic packing being retained in the upper gland; but here the retaining rings were of metal instead of vulcanite, and there was no leakage during the two years this packing was in use in the lower gland of the high-pressure cylinder of an engine when working at all powers from 2,000 to 12,000 H.P. In the case of an engine for running a dynamo the tightness was of corresponding duration. A development in the opposite direction has recently taken place, it having been found that under usual circumstances metallic packing is unnecessary for the piston and slide rods of the low-pressure cylinder. Soft packing in these positions behaves satisfactorily, and does not require the skill in attention and overhaul that many metallic systems involve. In the Navy most low-pressure glands are now being fitted with soft non-metallic packings.

The question of the coal consumption of auxiliary machinery has occupied much attention, and valuable data are to be found in the admirable Papers read at the Institution of Civil Engineers by Sir John Durston, K.C.B., Engineer-in-Chief of the Navy, and Mr. H. J. Oram, Chief Inspector of Machinery, and by Sir John Durston at the Institution of Naval Architects. There can be no doubt that a saving could be effected by compounding many of the engines, but in naval ships, at least, the necessary increase in weight is an objection. Flat slide-valves, with relief rings at the back where necessary, should replace piston slide-valves. Nearly all the piston slide-valves in the auxiliary machinery of naval ships, at all events, have, until recently, been solid, and although they may be tight when new they soon wear, with the result that constant leakage to the condenser goes on. Where such piston valves require to be fitted, they are now supplied with "restricted expansion" rings similar to those fitted to the main pistons.

The closed exhaust system of dealing with the exhaust steam from auxiliary machinery, introduced by Sir John Durston, consists in connecting the auxiliary exhaust mains to the evaporator steam coils, and to the L.P. cylinder chests of the main engines through suitable stop valves. The direct connections to the auxiliary condensers are kept closed by spring loaded valves set to lift when the pressure in exhaust pipes rises above a desired amount. Sentinel valves are fitted and set to blow off at 30 lbs. (above atmosphere). The result of this arrangement is that the condensers only receive such steam as the evaporators cannot condense in their heating coils. The connections to the L.P. chests when opened allow the exhaust of the auxiliaries to be used in the L.P. cylinders. The auxiliaries have to work against a higher back-pressure, but as they are at most two stage compound engines, this leaves them perhaps as large a range as is desirable, and steadies their running. The great advantage of the system is that it allows the latent heat of the exhaust steam to be usefully employed, instead of passing to the condenser.

It has been suggested that much of the auxiliary machinery should be operated by electricity, and it seems probable that where extensive use is made of the current, admitting of an economical system of generation, good results might accrue, especially in the driving of fans and other gear situated at present at considerable distance from the main steam leads. But the experience of some of the superintending engineers and also of the United States naval authorities, who have tried the electrical system "has not been altogether favourable." One difficulty to be guarded against is the application to such mechanism as requires a great initial impulse—as in the case of anchor gear, for instance, where the steam stored up overcomes a sudden and heavy load. There are reasons also for not adopting electric drive for any of the auxiliaries upon which the main engines are directly dependent. In the case of some of the auxiliaries, too, the efficiency must be the first consideration apart from economy.

Direct-Acting versus *Crank Pumps.*—In this connection, some results of trials made with crank shafts and direct-acting pumps are recorded on Table 17 (pages 664–5). The direct-acting pumps were all of the Weir standard pattern. The footnotes on Table 17 give the dimensions of cylinders and pumps in each case. It will be seen from the Table that the steam consumption of the crank-shaft pump, both when working high pressure and compound, is much higher than with the direct-acting pump, the steam consumption for the simple working being 67·8 lbs., as against a mean of about 48 lbs., whereas with compounding the difference is equally marked, and the mechanical efficiency is quite 10 per cent. better with the direct-acting pumps.

The Propeller.—The length of this Paper precludes any detailed reference to the subject of propellers. There is a growing tendency in favour of twin screws, largely because of the security they afford against complete breakdown, and something like 5½ per cent. of all steamers now constructed are of this type. Treble screws have been adopted for one or two merchant vessels for shallow river service, three-cylinder engines on the triple compound system being fitted athwart the ship with cranks running fore and aft, each driving a separate screw, and connected by a coupling rod at the forward end of each crank. This arrangement secured the advantage of triple expansion, and enabled the screws to be of less diameter than would have been the case with single or twin propellers. These instances, however, are exceptional. In naval practice there are several applications of treble screw propulsion, each screw having an independent engine. This system, however, was adopted not so much because it increased the propulsive efficiency at full power—it is very doubtful if such is the case—but because it enabled the centre engine and screw to be alone used for comparatively low speed, with the two side screws running idle so as to reduce the consumption at cruising speed; but it is possible that this may be achieved by other means, especially if the three propellers are found to reduce the propulsive efficiency. It may be incidentally mentioned that, to achieve the same result, an engine was built some years ago, in which a fourth or "additional" cylinder was introduced to act as a first stage cylinder or to be idle as the conditions suggested. The cylinder had all the necessary connecting pipes, passages, links and valves, but when the engine was working at full power, the piston of the added cylinder was retained in equilibrium, the steam passing to the second stage cylinder, where it worked at its initial or full pressure. When steaming at low power the extra cylinder came into operation, and thus there were four stages of expansion. This system was fitted to a Russian volunteer ship, the "Queen Olga," but the vessel has been continuously worked at full power, so that there are no data as to the actual economy under the varying speeds of naval manœuvring.

Steamship Speeds.—In the ten years considerable progress has been made in the direction of speed. In 1891 there were only eight vessels whose speed exceeded 20 knots, now there are fifty-eight, as shown in Table 16 (pages 662–3), which records the number of fast ships owned by the various nations at the end of last year and in 1891. The vessels between 19 and 19½ knots speed have doubled, numbering now 34; and Great Britain, it is interesting to note, holds a high position, due in part to the number of high-speed Channel steamers in the Irish Sea, North Sea, and English Channel. The French, Belgian, and Dutch high-speed steamers are principally Channel boats, but the five German vessels and the four of the United States are ocean liners. The highest speed attained ten years ago was 25 knots, recorded for a British-built Brazilian torpedo boat, the fastest British navy torpedo boat being 22½ knots; now the record is held by the steam turbine-propelled destroyer "Viper" of His Majesty's Navy, which has attained a maximum of 37·113 knots, and a mean for one hour of 36·581 knots. The highest ocean-speed ten years ago was 20·7 knots by the "Paris" and "New York": today the highest speed on an ocean run has been achieved by the German liner "Deutschland," which has maintained an average of 23·51 knots, while the best speed got with Channel steamers is that attained by the City of Dublin Steam Packet Company's steamers on the cross-channel run,—23·62 knots with steam of 171 lbs. pressure, the power being 8,500. These vessels, of 3,096 tons builder's measurement, have four-cylinder triple expansion type, with four double-ended boilers worked on the closed stoke-hold system.

A Comparison of High-Speed Steaming: Weights and Space Occupied.—On Table 14 (pages 656–9) there is given a list of dimensions of typical ships of today, including the two fastest Atlantic merchant vessels—the "Deutschland" and "Kaiser Wilhelm der Grosse"; the fastest armoured cruiser—H.M.S. "King Alfred"; the largest ship ever built—the "Celtic"; a typical Channel steamer with a cruiser of corresponding size, and, finally, a representative moderate-sized merchantman. There are several points of interest in the comparisons, but attention need only be called to one or two. It will be seen that the "Deutschland" is fitted with Howden's system of draught, the "Kaiser Wilhelm der Grosse" has an open stoke-hold with natural draught, and the "King Alfred" is fitted with the Belleville boilers: and here also we have a comparison between merchant and naval practice. The naval engineer has not only less space, but less weight, given him, the power per ton of machinery being almost double that in the correspondingly fast liners, while the superficial area occupied by the engine and boiler space per unit of power is about 25 per cent. less. The ratio of heating to grate area is 39 in Howden's system, 32 in the open stoke-hold system, and 31 in the Belleville boiler system. The comparison may be completed by a statement that in the case of the "New York" and "Paris," which were the fastest Atlantic vessels ten years ago, the power per ton of machinery was 6·75 I.H.P.—about the same as in the present day Altantic liners; the superficial area of machinery space 0·54 square foot per I.H.P., rather more than in the modern liner, and the ratio with the closed stoke-hold system of forced draught 38 square feet of heating surface per square feet of grate. Alike in the moderate-sized cargo steamer "Indrani" and in the "Celtic," the power per ton of machinery is about 50 per cent. less than in high-speed Atlantic liner practice, while the space occupied per unit of power is about double. The comparison of the Channel steamer "Duke of Cornwall," and His Majesty's second-class cruiser "Juno" or "Doris" is the more interesting, as both vessels have cylindrical boilers, and work with a closed stoke-hold. Here the naval ship, although working with a lower steam-pressure, has the advantage of a higher piston-speed, with lighter engine and boiler scantlings, and therefore gets 10·88 I.H.P. per ton of machinery as compared with 9 I.H.P. in the case of the Channel steamer.

It may be interesting here to compare the weights of machinery with those of ten and twenty years ago. In 1881, the average for merchant ships was recorded as 4·66 I.H.P. per ton, while in 1891 the average for cargo boats was 4·8, and is now about the same. For the fastest liner the weight ten years ago was also about the same as it is now—6·7 I.H.P. per ton, but generally there is now more boiler power and additional weight in the machinery. In Channel steamer work there has been an increase in the power per ton of machinery. In naval practice there has been a marked diminution in weight, the rate in 1881 being 6¼ I.H.P. per ton of machinery, in 1891 10 I.H.P. per ton, and now 12 I.H.P. all for natural draught.

As a complement to this Table, there is given on Table 15 (pages 660–1) a comparison of the space occupied by machinery in the latest built naval ships with cylindrical boilers, and with modern water-tube boilers, and in various types of merchantmen, including the high-speed Atlantic liners, "Kaiser Wilhelm der Grosse," "Deutschland" and "Campania," the immense cargo carrier, "Celtic," the Channel steamer "Duke of Cornwall," and the general trader, "Indrani." From this it will be seen that the Atlantic liners, with cylindrical boilers, require fractionally more stoke-hold floor space per unit of power than the Belleville boiler ships, the average being about 0·28 square foot, as compared with 0·25, while the cylindrical boiler war-ship required 0·35 as indicated by the figures for the "Majestic" and the "Crescent." In the case of the "Pelorus," which is fitted with a small tube express water-tube boiler, the space occupied is greatest, being 0·384. Turning to engine-room space, there is considerable variation, and it is to be noted that in the two latest classes of cruiser there has been a material reduction (0·11 square foot), although the "Campania," with her five cylinders and three cranks, Fig. 10 (page 624) comes out at a very low rate. But it should be remembered that whereas in the merchant ship there is no limit to the height of the engine, in war-ships the necessity for protection makes tandem cylinders impossible. The space occupied per unit of power in Atlantic liners is certainly satisfactory. Here there must be a great pressure put upon the designer to economise space, because of the great value of the area of the various decks. The average revenue per square foot of deck, excluding only engines and boiler spaces and uptakes, in one of the latest liners on the various decks is as follows:—

TABLE 7.—*Passenger Revenue possible on each Trip per square foot of Deck in Modern Atlantic Liner.*

	Summer.	Winter.
	per sq. ft. *s.* *d.*	per sq. ft. *s.* *d.*
Promenade . . .	7 6	4 11
Upper	5 10	4 2
Main	4 2	2 4
Lower . . .	4 3	2 4

When it is noted that this particular ship makes from twelve to fifteen round voyages in the year, it will be recognised that every square foot which the engine designer saves on the four decks indicated, ensures a possible yearly addition to the passenger earnings of £20, without any appreciable increase to expenses.

The Steam Turbine.—Any review of marine engineering progress would be incomplete without a reference to the possibilities of propulsion by steam turbines; but at the end of a Paper already too long, only a casual reference to the subject is possible. In electric-light work, the Parsons steam turbine has become a most efficient motor, and exhaustive trials have demonstrated its economy in steam consumption, the actual rate of a 1,000-kilowatt set having been 9·19 kilogrammes per kilowatt-hour, which may be accepted as equalling about 12½ lbs. per I.H.P.-hour. In the case of a long distance sea voyage at a uniform speed, and this is the condition prevailing in 99 per cent. of merchant steamers, there can be no doubt of the economy of the turbine. In such case, it can be designed for the maximum load, which would be the average working load. For naval work, where the speed is variable, the same advantages may not accrue, because the steam losses are practically constant irrespective of the power being developed. Where weight is a primary factor, even this need not militate against its adoption, and thus it would seem as if the future would see a great development in this direction. Plate 127 illustrates the design for a Parsons turbine-driven steamer of 7,000 H.P. with three shafts, two of which are driven by low-pressure turbines, while the centre shaft motor is of the high-pressure type. The turbines for driving the ship astern are incorporated with the low-pressure system, being fitted in the exhaust casings with a valve to pass the steam direct from the boiler to the astern turbines, in which case the low-pressure ahead turbines on the same shaft rotate in a vacuum. At the same time, the steam is cut off from the high-pressure turbine which also runs idle in a vacuum. It will thus be seen that for driving ahead the steam passes through the high-pressure turbine, thence through self-closing valves to the two low-pressure turbines, and finally to the condenser; but should the order be given to reverse the engines, the main admission valve is closed, and the steam is then passed through other valves to the two astern turbines, which being of large area develop considerable power and speed sternwards. The self-closing valves prevent the steam passing to the H.P. motor. The change is easily made, as all the valves are actuated from the same platform, and the arrangement is such that either of the side propellers may be driven ahead or astern separately. As to the relative space occupied, the sections, Plate 128, show the difference at a glance, and the weight and space occupied for turbine machinery and reciprocating engines of 7,000 I.H.P. are as follow:—

	Reciprocating engines.	Turbine machinery.
Weight in engine rooms and tunnel complete . .	270 tons	190 tons
Floor space in engine room .	911 sq. feet	911 sq. feet
Cubic capacity required by engines	14,430 cubic feet	10,500 cubic feet

The success of the Parsons turbine has brought several others into the field, and although experiments have been made at Barrow-in-Furness with several of these, they are not sufficiently advanced or conclusive to enable results to be given here. The season's work of the turbine driven steamer "King Edward," built on the Clyde, will also yield most important data.

SUMMARY OF RESULTS.

In conclusion, the author desires to acknowledge gratefully the services of many friends who have contributed data for this Paper, and to summarise briefly the results attained during the ten years. Steam pressures have been increased in the Merchant Marine from 158 lbs. to 197 lbs. per square inch, the maximum attained being 267 lbs. per square inch, and 300 lbs. in the Naval Service. The piston speed of mercantile machinery has gone up from 529 to 654 feet per minute, the maximum in merchant practice being about 900 feet, and in naval practice 960 feet for large engines, and 1,300 feet in torpedo-boat destroyers. Boilers also yield a greater power for a given surface, and thus the average power per ton of machinery has gone up from an average of 6 to about 7 I.H.P. per ton of machinery. The net result in respect of speed is that while ten years ago the highest sustained ocean speed was 20·7 knots, it is now 23·51 knots; the highest speed for large warships was 22 knots and is now 23 knots on a trial of double the duration of those of ten years ago; the maximum speed attained by any craft was 25 knots, as compared with 36·581 knots now; while the number of ships of over 20 knots was eight in 1891, and is 58 now. But probably the result of most importance, because affecting every type of ship from the tramp to the greyhound, is the reduction in the coal consumption. Ten years ago the rate for ocean voyages was 1·75 lbs. per H.P. per hour; today in the most modern ships, it is about 1·5 lbs. Ten years ago one ton of cargo was carried 100 miles for 10 lbs. of fuel, whereas now, with the great increase in the size of ships and other mechanical improvements, the same work is done for about 4 lbs. of coal—a result which means a very great saving when applied to the immense fleet of over-sea carriers throughout the world.

The Paper is illustrated by Plates 114 to 128 and 24 Figs. in the letterpress.

TABLE 8.—*Mean Results from Engineer's Log of Cunard Steamers*, 1899–1900.

Name of Vessel.	Voyage.	Speed in Knots.	I.H.P.	Revs. per Minute.	Stroke in Inches.	Piston Speed in Feet per Minute.	Coal Consumption.	
							Tons per Day.	Lbs. per I.H.P. per Hour.
S.S. "SAXONIA"	Liverpool to Boston	14·5	10,078	76	54	684	138	1·28
	Boston to Liverpool	15·0	10,230	77	54	693	136	1·24
S.S. "ULTONIA"	Liverpool to Boston	11·5	3,997	69	48	552	66	1·54
	Boston to Liverpool	11·8	4,292	71	48	562	62	1·35

The coal consumption given is for the propelling machinery, and does not include that used for refrigerating or galley purposes or port use, and is *therefore the actual amount of coal used at sea under ordinary conditions.* The mean consumption for the "Saxonia" = 1·26 lbs.; for the "Ultonia" = 1·445 lbs.

The "Saxonia" has a cargo capacity of 10,400 tons dead weight and 19,808 tons measurement of cargo to shelter deck, leaving the promenade and bridge deck for first and second-class passengers. The "Ultonia" carries 11,290 tons dead weight and 20,000 tons measurement to the shelter deck, which leaves the bridge deck clear for passengers.

TABLE 9.—*Sea-Voyage Performances of Steamers*

(Particulars supplied by British and

No. of Voyage.	Ports and Dates.	Steaming Time.			Distance Run.	Total Revolutions.	Revolutions per minute.	Speed		Slip per cent.	Mean Draught of Ship.	
		d.	h.	m.				by Screw.	by Ship.			
					knots.			knots.	knots.		ft.	ins.
	s.s. "BOMA." Built 1889.											
14	Liverpool to Teneriffe. *Oct.* 1893.	7	13	0	1660	608,430	56·0	9·67	9·16	5·3	17	1½
29	Liverpool to Teneriffe. *Feb.* 1898.	6	22	45	1660	602,760	60·2	10·39	9·95	4·2	18	6
33	Liverpool to Teneriffe. *May* 1899.	6	22	0	1660	599,210	60·1	10·37	10·00	3·5	19	9
39	Liverpool to Madeira. *Feb.* 1901.	6	9	0	1440	511,960	55·7	9·61	9·41	2·0*	19	3
	s.s. "LOANDA." Built 1891.											
9	Liverpool to Madeira. *Sept.* 1893.	5	23	30	1440	536,010	62·2	10·20	10·03	1·6	16	7½
10	Liverpool to Madeira. *Dec.* 1893.	5	6	17	1440	554,680	61·5	10·08	9·58	4·9	18	8½
12	Liverpool to Grand Canary. *July* 1894.	7	3	0	1660	611,950	59·6	9·78	9·70	0·8	16	10
36	Liverpool to Grand Canary via Madeira. *June* 1900.	7	10	15	1700	660,350	61·7	10·11	9·53	5·73	17	3

* Previous to Voyage No. 39 the ship was fitted with spare propeller having 77 square

built 1889–1893 (*continued on pages* 648–9).

African Steam Navigation Co.)

Average Displacement.	Average Dead Weight.	Average I.H.P.	Coal per day.		Kind of Coal and Report on Quality.	Coal per I.H.P.	Weather—Adverse.
tons.	tons.		tons.	cwts.		lbs.	
4264	2486	950	16	11	South Wales—fair	1·62	1 day—strong head, 6 days—light head.
4673	2895	1110	21	19	North Wales—swift and dirty	1·84	3 days—moderate head, 1 day—light head.
5047	3269	1160	23	2	North Wales—quick burning	1·90	3 days—strong following.
4897	3119	1100	22	12	45% Lancashire 55% North Wales quick burning	1·90	1 day—heavy following sea.*
4686	2726	870	15	15	South Wales—very good	1·69	1 day—strong head.
5352	3389	860	16	16	20% N. Wales 80% S. Wales good	1·72	Fair weather.
4756	2793	780	16	14	North Wales—good	1·99	Fair weather.
4888	2925	860	17	11	N. Wales mixed quality	1·90	2 days—light head.

feet of surface. Voyages 14, 29, and 33 were made with a propeller of 70 square feet surface.

TABLE 9 (*concluded*).—*Sea-Voyage Performances*

No. of Voyage.	Ports and Date:	Steaming Time.			Distance Run.	Total Revolutions.	Revolutions per minute.	Speed.		Slip per cent.	Mean Draught of Ship.	
		d.	h.	m.	knots.			by Screw. knots.	by Ship. knots.		ft.	ins.
	S.S. "BATANGA." Built 1893.											
2	Liverpool to Grand Canary. *March* 1894.	6	20	0	1660	640,840	65·1	10·67	10·12	5·1	16	4
6	Liverpool to Grand Canary via Teneriffe. *March* 1895.	6	22	50	1700	643,670	64·3	10·54	10·18	3·4	16	9
11	Liverpool to Grand Canary. *June* 1896.	6	14	30	1660	624,020	65·6	10·75	10·47	2·6	16	3
28	Liverpool to Grand Canary via Madeira. *July* 1900.	7	1	30	1700	675,900	66·4	10·89	10·03	7·9	17	11

Consumption of Coal per day as given includes consumption for steering engines, centrifugal circulating pump, and for *of Steamers built* 1889–1893.

Average Displacement.	Average Dead Weight.	Average I.H.P.	Coal per day.		Kind of Coal, and Report on Quality.	Coal per I.H.P.	Weather—Adverse.
tons.	tons.		tons.	cwts.		lbs.	
4679	2549	950	18	13	23% N. Wales 77% S. Wales fair	1·83	
4810	2680	950	19	0	North Wales—swift	1·87	
4653	2523	990	21	1	N. Wales quick burning	1·96	Fair weather.
5180	3050	1050	21	14	North Wales—fast	1·90	2 days—light head.

winches, pantry, heating purposes, etc., during the steaming time, and also includes dynamo in the two latter class steamers.

TABLE 10.—*Performances of Merchant Steamers;*

TRIPLE EXPANSION ENGINES,

(Particulars supplied by

Class. Date.	Description.	Length of each Voyage.	Ship. Length.	Ship. Breadth.	Ship. Depth.	Dead-weight. Tons.
		knots.	feet.			
"A" 1878	Results from 6 Steamers with Compound Engines. (Means of 7 Voyages) . . .	20,416	305—	34·85—	24·25	3,000
"A"	Results from same Steamers with Triple Expansion Engines. (Means of 7 Voyages)	20,504	305—	34·85—	24·25	3,000
"B" 1880	Results from 6 Steamers with Compound Engines. (Means of 10 Voyages) . . .	20,973	330—	40·2 —	26·3	4,200
"B"	Results from same Steamers with Triple Expansion Engines. (Means of 10 Voyages)	20,478	330—	40·2 —	26·3	4,200

first with Compound Engines, *and subsequently with*
to illustrate improved economy.

Messrs. Cayzer, Irvine and Co.)

Engines. Diameter of Cylinders. / Stroke.	Working Pressure.	I.H.P. mean.	Speed (Mean) knots.	Coal Consumption.		Knots per Ton of Coal.	System of Draught.
				Tons per day.	Lbs. per I.H.P. per hour.		
inches.	lbs.			Tons.	lbs.		
34—63 42	80	700	8·2	16·5	2·2	12·0	Natural.
22—34—59 42	160	1,000	9·5	15·0	1·4	14·8	Howden's Forced.
39—75 48	85	1,230	9·45	27·17	2·06	8·33	Natural.
24·5—40—67 48	180	1,650	10·4	24·25	1·37	10·2	Howden's Forced.

TABLE 11.—*Particulars of Cargo Steamers for North Atlantic Trade, to illustrate Fuel Economy of large capacity ships.*

Dimensions.	Draught.	Displacement.	Coefficient of Displacement.	Deadweight.	Speed at Sea.	I.H.P.	D. ⅔ constant.	Midship Area Immersed.	Girth Immersed.	Coal per 100 ton-miles.*
ft. ft. in. ft. in.	ft. in.	tons.		tons.	Knots.			sq. ft.	feet.	lbs.
390 × 45 9 × 29 6	24 6½	8,640	0·69	5,000	13	3,475	266	1,092	87·8	8·0
415 ,, 48 9 ,, 31 0	25 6	10,240	0·696	6,000	13	3,725	277	1,209	92·46	7·1
438 ,, 51 5 ,, 32 8	26 3½	11,870	0·702	7,000	13	3,970	287	1,314	96·46	6·5
458 ,, 53 9 ,, 34 0	27 0½	13,500	0·71	8,000	13	4,225	295	1,412	100·0	6·05
475 ,, 55 9 ,, 35 5	27 11	15,100	0·715	9,000	13	4,475	300	1,513	103·64	5·7
493 ,, 58 0 ,, 36 7	28 7	16,750	0·72	10,000	13	4,725	305	1,610	107·0	5·42
521 ,, 61 2 ,, 38 9	30 0	19,850	0·728	12,000	13	5,200	311	1,780	112·8	4·97
535 ,, 62 9 ,, 39 9	30 7	21,470	0·732	13,000	13	5,430	313	1,862	115·4	4·8
548 ,, 64 1 ,, 40 9	31 3	23,070	0·736	14,000	13	5,675	314	1,946	118·0	4·66
570 ,, 66 9 ,, 42 4	32 4½	26,150	0·742	16,000	13	6,130	316	2,097	122·5	4·4

All are Three-Decked Vessels (with Shelter Deck) to class 100 A 1 at Lloyd's.

* The rate of consumption is assumed in all cases at 1·5 lbs. per I.H.P. per hour.

TABLE 12.

Size of Ships launched in the United Kingdom, 1892–1900, *to illustrate Increase in Capacity.*

(Prepared from Lloyd's Registry Returns.)

Tonnage.	1892.	1893.	1894.	1895.	1896.	1897.	1898.	1899.	1900.
2,000 to 2,999	104	75	100	88	89	73	79	57	47
3,000 ,, 3,999	67	63	90	75	83	74	141	129	119
4,000 ,, 4,999	23	18	25	30	23	23	28	39	56
5,000 ,, 5,999	8	5	14	9	35	15	23	27	26
6,000 ,, 6,999	5	6	4	6	6	5	13	15	17
7,000 ,, 7,999		1	2	4	4	8	13	9	12
8,000 ,, 8,999					2	2	2	4	2
9,000 ,, 9,999							4		4
10,000 ,, 10,999						3		9	4
11,000 ,, 11,999					1				
12,000 and above				1					4

TABLE 13.—*Showing the Number of Large Ships*

(Prepared from Lloyd's

Tons.	All Countries.		Great Britain.		Germany.		France.		United States.	
	1891.	1901.	1891.	1901.	1891.	1901.	1891.	1901.	1891.	1901.
Vessels over 13,000	—	10	—	4	—	6	—	—	—	—
,, ,, 12,000	—	8	—	5	—	2	—	—	—	—
,, ,, 11,000	—	12	—	7	—	—	—	2	—	3
,, ,, 10,000	2	21	2	6	—	13	—	—	—	1
,, ,, 9,000	2	10	2	8	—	—	—	2	—	—
,, ,, 8,000	4	22	3	18	1	3	—	—	—	—
,, ,, 7,000	9	52	2	36	2	10	4	3	—	1
,, ,, 6,000	15	118	10	71	2	9	3	12	—	6
,, ,, 5,000	59	252	37	153	12	59	3	3	1	16

owned by Various Nations in 1891 *and* 1901.

Registry Returns.)

Russia.		Spain.		Belgium.		Italy.		Japan.		Holland.		Austria Hungary.	
1891.	1901.	1891.	1901.	1891.	1901.	1891.	1901.	1891.	1901.	1891.	1901.	1891.	1901.
—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	1	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	1	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	1	—	—
—	2	—	—	1	—	—	—	—	—	—	—	—	—
—	1	—	1	—	1	—	—	—	16	—	—	—	1
—	9	3	4	2	3	1	—	—	1	—	1	—	3

TABLE 14 (*continued to page* 659).—*Dimensions and Weights of Machinery of Typical Modern Steamers* (*see page* 624).

Name of Ship.	"DEUTSCHLAND."	"KAISER WILHELM DER GROSSE."	H.M.S. "KING ALFRED."
Builders	Vulcan Co., of Stettin.	Vulcan Co., of Stettin.	Vickers, Sons and Maxim, Barrow.
Owners	Hamburg-American.	North German Lloyd.	British Admiralty.
Year when completed	1900	1898	Now Building
Length over all	684′ 0″	648′ 7½″	529′ 6″
,, between perpendiculars	662′ 9″	625′ 0″	500′ 0″
Breadth	67′ 0″	66′ 0″	71′ 3″
Depth (Moulded)	44′ 0″	43′ 0″	39′ 6″
Gross Tonnage . . . tons	16,502	14,349	8,700
Draught	29′ 0″	28′ 0″	25′ 10¼″
Displacement . . . tons	23,620	20,880	14,200
Type of Engine	6 Cylinders, Quadruple Expansion—Schlick System	4 Cylinders, Triple Expansion—Schlick System.	4 Cylinders, Triple Expansion—Yarrow, Schlick and Tweedy.
Number of Cranks	4	4	4
Diameter of Cylinders in each Engine	$103{\cdot}9''-\frac{36{\cdot}6''}{106{\cdot}3''}-\frac{36{\cdot}6''}{106{\cdot}3''}-73{\cdot}6''$	52″–89·7″–96·4″–96·4″	81½″–43½″–71″–81½″

TABLE 14 (*continued on next page*).—*Dimensions and Weights of Machinery of Typical Modern Steamers.*

Name of Ship.	"DEUTSCHLAND."	"KAISER WILHELM DER GROSSE."	H.M.S. "KING ALFRED."
Stroke of Piston	72·8″	68·8″	48″
Piston Speed . . ft. per min.	—	885	960
Number and Type of Boiler	12 D. E. and 4 S. Ended	12 D. E. and 2 S. Ended.	43 Belleville with Economisers.
Number of Furnaces	112	104	43
Steam Pressure . . . . lbs.	220	178	Boilers 300, Engines 250
Total Heating Surface . sq. ft.	85,468	84,285	72,001
Total Grate Area . . sq. ft.	2,188	2,618	2,313
System of Draught	Howden's	Open Stokehold	Natural
Total Indicated Horse-Power	38,900	30,000	30,000
Highest Mean Speed . . knots	23·51	22·79	23
Superficial Area of Engine and Boiler Spaces per I.H.P. . . sq. ft.	0·382	0·42	0·316
Total Weight of Machinery, including Water . . . . . tons	5,670	4,460	2,500
I.H.P. per ton of Machinery	6·86	6·71	12

TABLE 14 (*continued*).—*Dimensions and Weights of Machinery of Typical Modern Steamers.*

Name of Ship.	"CELTIC."	"DUKE OF CORNWALL."	"JUNO" and "DORIS."	"INDRANI."
Builders	Harland and Wolff, of Belfast.	Vickers, Sons and Maxim, Barrow.	Vickers, Sons and Maxim, Barrow.	Vickers, Sons and Maxim, Barrow.
Owners	White Star	L. and N. W. Ry. Co.	British Admiralty.	T. B. Royden and Co.
Year when built	1901	1898	1896	1894
Length over all	697′ 5″	325′ 6″	370′ 3″	411′ 2″
„ between perpendiculars	680′ 0″	315′ 0″	350′ 0″	399′ 9½″
Breadth	75′ 4¼″	37′ 0″	54′ 0″	47′ 11″
Depth (moulded)	48′ 4½″	17′ 6″	34′ 1⅜″	32′ 3″
Gross Tonnage . . . tons	20,880	1540	3,773	4,994
Draught	33′ 0″	15′ 3¼″	20′ 6″	25′ 0″
Displacement . . . tons	33,550	2,830	5,600	10,930
Type of Engine	4 Cylinders, Quadruple Expansion	4 Cylinders, Triple Expansion—Yarrow, Schlick and Tweedy.	3 Cylinders, Triple Expansion.	3 Cylinders, Triple Expansion.
Number of Cranks	4	4	3	3
Diameter of Cylinders in each Engine	33″–47½″–68″–98″	22½″–34″–38½″–38½″	33″–49″–74″	27″–44″–72″

TABLE 14 (*concluded from page* 656).—*Dimensions and Weights of Machinery of Typical Modern Steamers.*

Name of Ship.	"CELTIC."	"DUKE OF CORNWALL."	"JUNO" and "DORIS."	"INDRANI."
Stroke of Piston	63″	33″	39″	48″
Piston Speed . . ft. per min.	—	880	910	640
Number and Type of Boiler . .	8 Double Ended	4 S. E. Cylindrical	8 S. E. Cylindrical	2 D. E. Cylindrical
Number of Furnaces	48	16	24	8
Steam Pressure . . . . lbs.	210	180	155	180
Total Heating Surface . sq. ft.	41,680	10,772	18,750	6,108
Total Grate Area . . sq. ft.	1014	317	599	192
System of Draught	Assisted Draught	Closed Stokehold Forced	Closed Stokehold Forced	Natural
Total Indicated Horse-Power . .	13,000	5,520	9,830	2,120
Highest Mean Speed on Passage . knots	16·0	19·75	20	10·75
Superficial Area of Engine and Boiler Spaces per I.H.P. . . sq. ft.	0·96	0·405	0·44	949
Total Weight of Machinery, including Water . . . . . tons	2,975	612	904	455
I.H.P. per ton of Machinery . .	4·37	9·02	10·88	4·66

TABLE 15.—*Space Occupied by Machinery in Typical Modern Naval and Merchant Ships.*

Type of Ship.	Name of Ship.	Type of Boiler.	Steam Pressure.		I.H.P. designed.	Floor Space.						
			Boilers.	Engines.	(*a*) Full Power F.D. (*b*) Full Power N.D. (*c*) Continuous.	Engine Room.			Boiler Room.			Total Sq. Feet per I.H.P.
						Length ×	Mean Width.	Sq. Feet per I.H.P.	Length ×	Mean Width.	Sq. Feet per I.H.P.	
						feet.	feet.		feet.	feet.		
Battleship, 1895.	"MAJESTIC"	Cylindrical	155	150	(*a*) 12,000 (*b*) 10,000 (*c*) 6,000	43·5 ×	46·0	(*b*) ·200	79·5 ×	45·5	(*b*) ·362	(*b*) ·562
Battleship, 1900.	"DUNCAN"	Belleville	300	250	(*b*) 18,000	52·0 ×	46·25	(*b*) ·133	94·0 ×	45·5	(*b*) ·238	(*b*) ·371
Cruiser, 1892.	"CRESCENT"	Cylindrical	155	150	(*a*) 12,000 (*b*) 10,000 (*c*) 6,000	40·0 ×	46·0	(*b*) ·184	93·5 ×	37·0	(*b*) ·345	(*b*) ·530
Cruiser, 1900.	"HOGUE"	Belleville	300	250	(*b*) 21,000 (*c*) 16,000	60·0 ×	47·5	(*b*) ·136	99·0 × 33·0 ×	44·0 34·0	(*b*) ·26	(*b*) ·396
Cruiser, 1901.	"KING ALFRED"	Belleville	300	250	(*b*) 30,000 (*c*) 22,500	67·5 ×	47·33	(*b*) ·106	90·0 × 45·0 × 45·0 ×	43·75 40·75 32·0	(*b*) ·24	(*b*) ·346

Cruiser, 1901.	"MONMOUTH" Class	Belleville and Niclausse	300 250	(b) 22,000	59·0 × 41·0	(b) ·11	90·0 × 39·0 45·0 × 34·0	(b) ·229	(b) ·339
Cruiser, 1896.	"PELORUS"	Normand	300 250	(a) 7,000 (b) 5,000 (c) 3,500	37·8 × 34·0	(b) ·257	80·0 × 24·0	(b) ·384	(b) ·640
Torpedo Boat Destroyer, 1900.	"VIXEN"	Vickers "Express" type.	250 240	(a) 6,000	29·0 × 18·0	·087	66·5 × 13·75	·152	·239
Channel Steamer	TSS. "DUKE OF CORNWALL"	Cylindrical	180	(a) 5,517	27·0 × 33·75	(a) ·165	40·0 × 33·0	(a) ·24	(a) ·405
Cargo Steamer	SS. "INDRANI"	Cylindrical	180	(b) 2,120	28·4 × 32·5	·436	32·0 × 34·0	·513	·949
Atlantic Liner	"KAISER WILHELM DER GROSSE"	Cylindrical	178	(b) 28,000	72·0 × 55·0	·14	73 × 54 73 × 54	(b) ·28	(b) ·42
Atlantic Liner	"DEUTSCHLAND"	Cylindrical	220	(a) 35,000	87·0 × 56·0	·139	80 × 55 80 × 54 62 × 21	·286	·425
Inter-mediate Liner	"CELTIC"	Cylindrical	210	(b) 13,000	—	—	—	—	·96
Atlantic Liner	"CAMPANIA"	Cylindrical	165	(b) 30,000	About 50·0 × 56·0	·093	About 82·5 × 55·5 67·5 × 55·5	·277	·371

TABLE 16.—*Showing the Number of Fast Ships owned*

(Prepared from Lloyd's

Vessels.	All Countries.		Great Britain.		Germany.		France.	
	1891.	1901.	1891.	1901.	1891.	1901.	1891.	1901.
20 knots and over .	8	58	8	32	—	5	—	7
19 and 19½ knots .	17	34	8	21	6	2	—	3
18½ knots . .	6	8	5	5	1	3	—	—
18 ,, . .	13	39	12	33	—	2	—	—
17½ ,, . .	24	26	11	13	3	1	10	12
17 ,, . .	18	64	13	42	4	1	1	5
16½ ,, . .	24	23	—	15	—	1	—	5
16 ,, . .	9	70	17	41	2	7	1	3
15½ ,, . .	43	34	5	13	—	8	1	1
15 ,, . .	41	121	38	78	—	4	3	8

by the Principal Maritime Nations in 1890 *and* 1901.

Registry Returns.)

United States.		Belgium.		Russia.		Holland, Austria-Hungary, Italy, Japan, Roumania, Chili, Spain, Sweden, and Denmark.	
1891.	1901.	1891.	1901.	1891.	1901.	1891.	1901.
—	4	—	6	—	1	—	3
—	—	3	3	—	4	—	1
—	—	—	—	—	—	—	—
—	—	—	—	—	—	1	4
—	—	—	—	—	—	—	—
—	5	—	3	—	—	—	8
—	1	—	—	—	—	—	1
1	10	—	—	—	—	3	9
—	9	—	—	—	—	3	3
—	16	1	1	—	2	1	12

TABLE 17.—*Steam Consumption Trials of*

Working Non-Condensing.			
Type of Pump	Crank-Shaft Pumps.		
Simple or Compound	Simple.	Compound.	Compound.
Trial No.	A	B	C
Duration of Trial . . . min.	30	30	30
Steam Pressure at Pump lbs. per sq. in.	127	157	99
Revolutions . . . . . total	383	619	282
Revolutions . . . . per min.	12·76	20·63	9·4
Displacement of Bucket . total lbs.	21,050	34,045	15,510
Displacement of Bucket . per rev.	55	55	55
Water Pressure on Gauge lbs. per sq. in.	180	50	35
Mean Water Pressure on Bucket lbs. per sq. in.	179·75	51·88	34·62
Steam used Condensed and Weighed lbs.	364	123	54
Steam used . . . . per rev.	0·95	0·1988	0·1915
Water per lb. of Steam . . . lbs.	57·9	277	287·5
Ft.-lbs. Work on Steam Cylinder per lb. of Steam	29,200	41,490	27,250
Ft.-lbs. Work on Pump per lb. of Steam	24,040	33,200	23,000
Steam per I.H.P. . . . . lbs.	67·8	47·8	72·7
Steam per W.H.P. . . . . lbs.	82·5	59·7	86·2
Mechanical Efficiency	0·824	0·802	0·844

TRIAL A was made with a Simple Crank Shaft Feed-Pump (Weir make), having Two Steam Cylinders 8½ in. diam., Two Pumps 6½ in. diam. × 12 in. Stroke.

TRIALS B and C were made with a Compound Crank Shaft Feed-Pump (Weir make), having Two Steam Cylinders 5 in. and 8½ in. diam., Two Pumps 6½ in. diam. × 12 in. Stroke.

Crank-Shaft and Direct-Acting Pumps.

Working Non-Condensing.				
Direct-Acting Pumps.			Direct-Acting Pumps.	
Simple.	Simple.	Twin Compound.	Simple.	
D	E	F	G	H
120	30	30	30	30
108	147	140	106	98
1,499	733	308	358	189
12·45	24·43	10·26	11·93	6·3
43,471	153,343	72,500	42,200	22,300
29	209·2	235	118	118
156	75	180	190	180 to 195
160·45	73·3	187·8	182·2	186·2
498	532	535	488	284
0·3307	0·7265	1·738	1·363	1·502
87·7	288	135·75	86·5	76·4
37,250	51,830	63,710	40,000	36,610
32,500	48,720	58,970	36,300	33,650
53·2	38·2	31·1	49·5	54·1
61	40·6	33·6	54·6	58·9
0·873	0·941	0·926	0·908	0·919

TRIAL D was made with a Weir Direct-Acting Pump (feeding a Boiler), having Steam Cylinder 8 in. diam., Pump 6 in. diam. × 15 in. Stroke.

TRIAL E was made with a Weir Ballast Pump, having Steam Cylinder 10 in. diam., Pump 12½ in. diam. 24 in. Stroke.

TRIAL F was made with a Twin Compound Weir Pump, having Steam Cylinders 14 in. and 26 in. diam., Pumps 9½ in. diam. × 24 in. Stroke.

TRIALS G and H were made with the High-pressure half of the Twin Pump, having Steam Cylinder 14 in. diam., Pump 9½ in. × 24 in. Stroke.

Discussion.

The PRESIDENT thought there could be no two opinions as to the value of the Paper which had just been read, but there was one serious mis-statement in it which affected him personally, and which he wished to correct before the discussion was commenced. On the first page (page 607) the author said: "As to the selection of the author, the responsibility is the President's, and he was doubtless influenced solely by the fact that this year's summer meeting is being held at Barrow-in-Furness." It was quite true that he asked Mr. McKechnie to read the Paper, but the reason for asking him was not correctly stated. He asked him because he thought Mr. McKechnie was the right man for the job, and he was quite sure he was correct in the selection. The fact that Mr. McKechnie was associated with Barrow-in-Furness was a happy accident. He wished to propose a hearty vote of thanks to the author for his valuable contribution.

Mr. BRYAN DONKIN, Vice-President, wished to add his high appreciation of the excellent Paper which had been read. It contained a mass of facts which were extremely well collected, and embodied in Tables with great care and skill. He would like to ask how the author ascertained, as stated (page 623), "that the vertical vibration measured at the extremity of the 684-foot ship was only $\frac{3}{16}$ inch."

In ships the heating of the air for combustion mentioned in the Paper was a most important point for economy, ensuring better combustion and diminution of smoke. He hoped that some system would be adopted in the Royal Navy, as it appeared to be very largely and successfully used in the Mercantile Marine. There seemed to be a large field for mechanical stoking of boilers at sea, nevertheless nothing had yet been done and no experiments made. Those members who had been on board ships, and into the stoke-holes, as he had had the privilege of doing occasionally, knew that their greatest anxiety was to get out of them again. The heat in the stoke-holes and the coal dust in the air that the stokers had to work in, even during short watches of three or four hours, was something too painful and horrible to think of; in hot climates it was worse. Mechanical stoking was in use on land in many places, and there was no particular difficulty in using it for constant loads. It seemed to him that such stoking at sea offered an immense field for the boiler mechanical engineer. Superheating also seemed to be a new field which might largely be adopted for economical reasons. If engineers were afraid of the high temperature of the superheat, they ought to slightly superheat the steam in order to get it dry in the high-pressure cylinder. On land, both in America and England, the steam was often heated and dried between the cylinders with advantage. He did not know whether such had yet been adopted in marine practice. The pistonless rotary steam turbine, which had been slightly touched upon, seemed to be the engine of the future for modern ships, as against the reciprocating piston type. He quite agreed with the remarks of the author on that subject.

It might interest the members to know, dealing with the steam-jacket question, that there was still a Steam-Jacket Research Committee, although it had not been very active of late. It was stated in the Paper that "recent trials with H.M.S. 'Argonaut' showed that better results were got without using steam in the jackets." Did that mean all the jackets? or which jacket of the three or four? One would also like to know the pressures of the steam in the various jackets during the trial. Hardly sufficient data were given. The author also stated in the same connection, "There can be no doubt that as the steam pressures increase, the use of steam in jackets will be dispensed with." He hardly agreed with that remark. Probably they would be dispensed with in the high-pressure cylinders, but they ought for best economy to be adopted in the intermediate, and especially in the low-pressure cylinders. It would be of interest if the author would give some information as to how the liners were fixed steamtight in the outer cylinders. Jackets were generally adopted at sea, although the steam was not always introduced into them, except at starting the engines. Various methods had been brought before the Steam-Jacket Committee, but the members would probably like to know the best system now adopted to secure a tight joint between the liners and the cylinders, either with copper rings or other arrangements.

M. le Professeur SAUVAGE said that it seemed to result from the examples given that the valves should continue to be used on low-pressure cylinders; and he questioned whether the piston valve ought not to be as much applied even to the low pressure as it was to the high and intermediate-pressure cylinders? Of course he did not refer to the auxiliary machinery, where it was shown that on small engines the use of the piston valve was not always desirable; he spoke only of the main engines. Another very important point was the superheating of the steam. Certainly from the theoretical point of view the superheating of steam was of great importance for fuel saving, but he believed there was a great difficulty in applying in a good way the superheating of the steam, especially on board ships. That difficulty resulted in part from the use of the ordinary cylindrical boiler. If good superheating was required to be done, the temperature of the steam must be raised at least to about 50° or 60° Centigrade, or 80° or 100° Fahrenheit. If the superheat was put into the up-take in order to remove the waste heat from the gas, it worked under two difficulties. In the superheat one must have the highest temperature of the steam, but then outside the superheat was put the lowest temperature, and so the rate of transmission of heat from the hot gases to the warm steam was rather low, that is, a small quantity of heat passed in a given time through the plates from the gases to the steam. The members were perfectly aware that another plan had recently been resorted to, namely, not to place the superheater after the boiler proper, but in a place where the gases were still very warm. Of course it could not be placed on the fire itself, because the plates would be destroyed, but it was placed in an intermediate part, where the gases were still hot enough to give a good transmission of heat. The second point he wished to mention was that the transmission of heat for a difference of temperature was not so rapid with dry steam as with water. The transmission of heat from hot gases to dry steam he believed was not so great in a given time as from the same gases to water, but that of course could not be avoided. It seemed a very difficult problem, especially if the cylindrical boiler was retained, which seemed advisable, to get a good superheater, unless it was given a very large heating surface, which meant a great deal of space and weight.

He would be much obliged if the author could supply a few more details with respect to forced lubrication. It seemed to be a very sensible plan to use forced lubrication, not only in very high-speed engines, in specially enclosed engines, but in every engine. Was it not possible that by using forced lubrication with proper appliances a great saving might be made in the lost power by friction? He believed that was a new field of investigation for marine as well as land engineers.

Mr. Henry McLaren said he was very pleased to hear the author's remarks about piston valves, because he considered the piston valve was the refuge of the destitute. When all things failed, and when no other valve could be made to run, piston-valves had to be used, and the engines then ran nicely, but very extravagantly. He obtained his experience of piston-valves 25 or 30 years ago—at other people's expense. He had never put a piston-valve on an engine at his own expense. He made principally large electric-lighting engines running at high speeds, and was now making engines of 2,500 H.P., with balanced slide-valves on all the cylinders, running at 200 revolutions per minute. The low-pressure cylinder was 62 inches diameter, therefore the valves were of a considerable size, and were balanced very much in the same way that the author had balanced his. He found that the surface speed at which the valves were run was a very important factor. For instance, supposing one had an engine running with a valve speed up to 200 feet per minute, balanced, if the speed was then run up to 300 or 330 feet per minute the valve faces would probably cut. He had known balanced slide-valves run perfectly with a speed of 200 feet per minute with superheated steam, but when the speed was increased to 300 feet and using steam from the same boilers, it was found that the high and the intermediate did not cut, because they had been balanced very carefully, but the low-pressure valves, which were only working with 10 or 12 lbs. in the steam-chest, started to cut and had to be more balanced, when they also worked perfectly.

(Mr. Henry McLaren.)

These speeds referred to the low-pressure valves only; there was no trouble with the high or intermediate valves cutting, as they were largely balanced, and ran less surface speed, being a shorter stroke than the low-pressure valve. The amount of balance was a very important point, to which he had devoted a great deal of time. He started with balancing the area of the exhaust cavity in the valve. That was very satisfactory, as long as the steam-pressure and the speed of the valve were not too high. Many of his engines were working with superheated steam somewhere about 100 or 120° F., and all contained ordinary D valves balanced. He maintained that in electric-lighting stations where there were a large number of engines, the simple engine would always win if it could be made economical in steam. There was no fault to find with the economy, because with his engines running with 160 lbs. of steam non-superheated, they did 12 lbs. of steam per I.H.P., 20 lbs. per kilowatt, and could average on $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, and full load, 24 lbs. per kilowatt. He was endeavouring to impress upon the members that the simple engine with three ordinary slide-valves, three pistons, and piston rods, could do as well as engines with all the fancy valve-gears ever made. The author had given some illustrations of balance rings (page 627). His own rings were very similar to those, in fact he noticed when the engines of H.M.S. "Powerful" were illustrated in the engineering papers that the balance rings were almost identical with his. On Fig. 45 it would be seen that the Ramsbottom packing rings were on the outside of the balance ring. When he put them on as shown, he opened out the mouth of the balance ring at A until it was $\frac{1}{16}$ inch larger than at B where the packing rings fitted. Thus the steam-pressure always kept the balance ring up to its face, in fact it could be

Fig. 45.

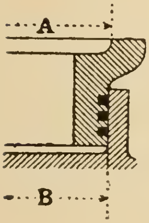


Fig. 46.

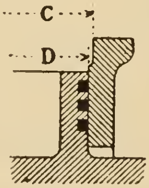
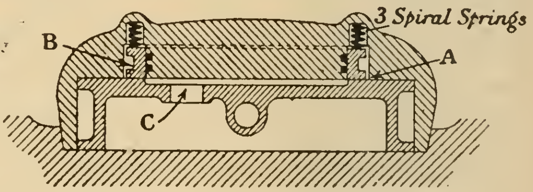


Fig. 47.

Section through Valve, Saddle, and Balance Ring.



run without any springs. For high-speed engines the balance rings were always put on the covers. With the slow-speed engines it was more convenient sometimes to put them on the valves. He fitted his packing rings mostly inside the balance ring, as shown at Fig. 46. Opening out the mouth at C $\frac{1}{16}$ inch larger than D, these rings were found to work well, springs only being provided to keep the ring up to the face when the steam was shut off. On short and wide valves where he could not find room for one ring of sufficient area, he put two of smaller size side by side. Electric-lighting work was performed under different circumstances to that of marine. In marine or locomotive work there was very little pressure in the steam-chest when the engines were doing light work, whereas in electric-lighting engines fitted with automatic cut-off gear there was always full boiler pressure in the steam-chest at light loads, and practically no pressure in the cylinder. Under these circumstances of course the valves were very much more liable to cut. To prevent them cutting he had balanced the whole of the cavity in the valve plus one of the steam-ports, and no difficulty was experienced. The pressure due to the springs was not important, because even if a few cwts. were put on, they were only equal to one or two square inches of the valve left unbalanced with the boiler pressure behind it, and would make very little difference unless they were very heavy springs. Piston-valves were used very largely on electric-lighting engines, a throttle-valve governor being also used; the trouble from leaky valves was not so pronounced as with automatic-expansion governors. The main valve on his 2,500 H.P. engine was driven by a shaft governor of his own make. Those governors were also made for other people who put them on to piston-valves, but if that was done his firm took no responsibility with regard to the governing. The governors acted very well at first, as long as the valves were tight, but immediately the piston-valves got a little worn the engine would run away, at light loads, and the governor got the blame. This went to prove that valve leakage of a piston-valve engine soon became very large indeed. He had repeatedly made experiments with piston-valve engines, when the valves to all appearance were in perfect order, yet they passed so much steam that it made the

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control of the governor of no effect. He was therefore of necessity compelled to get slide-valves for tightness, economy then resulting; the longer they ran the tighter they got. The main difficulty he found in high-speed engines was in keeping the low-pressure valve on its face before the load came on the engine. It would be the same if the low-pressure valve was not balanced, because they were working with the full pressure in the H.P. steam-chest, the high-pressure engines running the engine up to speed; the low-pressure piston was pumping, and it clattered the valve off its face until the load came on. That was not permissible in an electric-lighting station, so provision had to be made for keeping the valve on the face. In order to accomplish this he carried out the following system. Most of the members had seen the American system of putting a very heavy saddle over a valve, and then working with what he might call a flat piston-valve. The valve was fitted very nicely in saddle, as shown in Fig. 47 (page 670), but this valve would blow through at A when worn just as readily as a circular piston-valve. He sometimes used this saddle, but a circular balance ring B was always introduced as well, so that if the valve wore, the balance ring which had springs behind it took up the wear preventing steam leakage, and the saddle prevented the main valve from knocking off the face, when the engine was running at full speed with no load. A hole C through the back of the valve equalized the pressure on each side. He had recently seen one of his triple-expansion engines opened out, which had been at work for over two years, using superheated steam, and running 333 revolutions per minute. He found no wear on the high or intermediate valves, and the wear on the low-pressure face only amounted to $\frac{6}{1000}$ inch. This engine was a 600 I.H.P. condensing electric-lighting engine.

Mr. A. Basil Wilson wished to make a few remarks on the factor of safety for boiler shells mentioned in the Paper (page 613). The author there stated that the Board of Trade figure was 4·5, and the Admiralty 3·9. Now since the question of Scotch *versus* Tubulous Boilers was agitating the public mind largely at the present time, this was a matter of considerable importance. The drawback to the

Scotch boiler, so far as the merchant service was concerned, chiefly arose from its weight, it being remembered that, in vessels registered in Great Britain, the question of space for propelling machinery might in many cases be neglected except in vessels of high speed. In the ordinary cargo-boat the room for propelling machinery frequently fell short of the space required to obtain the proportion between it and the total contents of the ship to obtain the full reduction in registered tonnage, and it frequently happened that artificial and for other purposes unnecessary space had to be provided for this purpose. In mercantile work, therefore, as distinguished from naval, under the rules as they were at present, reduction of weight was alone of permanent advantage to the ship owner, enabling more cargo to be carried and increasing the earnings of the vessel. Since the Institution has always taken a prominent interest in progress and in the elimination of unnecessary material, their opinions and influence might be directed to this subject with great advantage to those interested in the carrying trade, to whom any reduction in dead weight in steam vessels would be a direct boon. The question, therefore, as to why a merchant steamship should have to carry boilers, roughly speaking 15 per cent. heavier than a man-of-war, was worth enquiring into. There seemed to him to be two main reasons for this weight. First, the method of reckoning the factor of safety, and second, considerations of wear and tear. As to the first. Were we right in basing the factor of safety on the ultimate fracture of the sample tested? He thought not. Boilers did not fracture; they wore out and leaked. It was an unknown thing for a properly constructed and carefully tended boiler to explode, and it was equally well known, on the other hand, that extra strength and care in construction did not prevent disastrous results in badly attended boilers, and we have now passed away from what he might call the mediæval ideas of sudden increases of pressure and spontaneous explosions. In taking the ultimate fracture as a basis of scantling calculations, they took the exploding point, not the wearing point; and since the wear, apart from corrosion, arose entirely from strains which must be well within the elastic limit to ensure a fair life to the apparatus as a

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whole, he would contend that this elastic limit was the basis on which the factor of safety should be calculated. Steel is as elastic as indiarubber. The various qualities of rubber had full recognition as to their elastic values for the purpose for which they were applied. The corresponding quality in steel was, so far as he was aware, not recognised in constructional work. Secondly, as to considerations of wear and tear. Information on this subject was not obtainable from new boilers, but from those ten, fifteen or twenty years old; and taking the average life of a marine boiler at fifteen years, the condition it was in at seven should form the guide for construction. At present the idea was that a new boiler should be so designed that, if pressed to 4½ times its working pressure, it would go off like a shell, every portion of it giving way simultaneously. After ten years of wear a very different condition of things came into existence, and a design which would provide for the simultaneous fracture of all the parts on being overstrained at that period would be the ideal one, and would be a considerable reduction on the original weight. Experience was not obtainable from a new pair of boots, but from an old pair; the existing rules, so to speak, made the soles and the uppers of the same strength and section of material: the former wore, the latter did not. He thought, therefore, the uppers as represented by the shell, ends and steam-space stays, might well be reduced, and the soles such as tubes, combustion chambers and under-water stays kept at their present strength.

He wished to refer to the question of piston-valves which had been raised in the discussion, and a comparison made between marine and land work, especially electric. In marine work the piston-valve was undoubtedly the survival of the fittest; they all ran vertically, they had to go for many days without attention; and lastly, they had to run practically without oil. The quantity of lubricant that could be safely admitted into a marine engine, and which might find its way into the boilers, must necessarily be exceedingly limited. It had been found, therefore, that piston-valves, though not perfect, gave good results, and their use had crept from the high to the intermediate, and from the intermediate to the second intermediate, if there was such a cylinder, till at length the low pressure was the only cylinder in many instances in which a slide-valve was fitted. The difficulties of leakages in connection with these had almost disappeared. The loss of steam through such valves has been almost the inverse ratio of their complication and multiplicity of details. Packing rings in piston-valves were rapidly resolving themselves into a single ring adjustable in diameter by the insertion of liners in a diagonal parting. A good fit and with no spring. Such valves lasted in tramp steamers without alteration for many years, and with none of the destructive barrelling of the ports and valve linings, and seemed to be quite indifferent as to whether they got oil or not.

The question of vibration had been referred to, especially in connection with its absence in the German ship "Deutschland." He would point out, however, that its presence in some ships and absence in others was not entirely dependent on the perfection of balances in the engines. Every vessel had its own critical speed at which it would vibrate, if the impulses derived from unbalanced weights, unequal turning moment, or the action of the propeller blades corresponded, and so far as he knew calculations were inadequate to determine whether they would or would not correspond; the steadiness or otherwise was to a great extent a matter of chance. It seemed to him that steadiness of turning moment, which Mr. A. Holt had found of great importance, had hardly received the consideration it deserved, not from the vibration aspect, but rather from that of continuous thrust, and the avoidance of the "row boat" action with an interval between the impulses as compared with the continuous thrust obtained in an ideal perfection by the turbine engine. Comparisons were frequently made between the duties of land and marine steam machinery, and the finger of scorn had been somewhat pointed to the absence of their many refinements, such as steam jacketing and spring released valves. In marine work no doubt there were many tons of coal which might be saved by such additions, but so far they had not met with much success or appreciation. It must be borne in mind that owing to the large volumes of feed water to be dealt with, and the limited space and conveniences, coal consumption was the only practical test, and that alone might be frequently misleading. Accurate tests, which could be made with facility in land work, were impossible at sea, and it was quite possible that the apparatus which would produce considerable economy in smooth weather, might have just the reverse effect in bad. Bearing in mind the high price of coal, especially in foreign ports, and the fact that each ton of coal shut out a corresponding weight of cargo, increased efficiency in marine engines was a much more fascinating subject than in land engines.

The two lines on which improvement seemed possible were, drier steam and less clearance spaces and surface. Notwithstanding the difficulties involved, the next few years would doubtless see great advances in this direction.

Reference had been made to mechanical stoking: so far as he knew this had not been successful on board ship. No mechanical stoker had yet been devised, nor was it conceivable it could be constructed to adapt itself to the various angles of the ship. A vessel, especially when light, with a beam wind, would lie with a list of 25 degrees for many minutes at a time, the coal on the bars would all work over to the lee side, in fore and aft fired boilers, or be delivered over the bridge on the lee, and half way along the bars on the weather side in thwartship-fired boilers. The stoker that would suit for Welsh might not accommodate itself to Scotch, or possibly still less to American coal. On the whole, however, the stoker's life was not such a bad one; he had a "halo" of coal dust around him in which he posed as a "hardly used" member of the crew. It would be remembered that his watch was only half that of the deck hands, that he had no exposure to the weather, and that he had plenty of fresh air and ventilation; his lot was not so unhappy, and though mechanically dirty, they were physically the cleanest men in the ship, and the best off.

Mr. A. Tannett-Walker, Member of Council, thought the Institution and the members were placed under a very deep debt of gratitude to the author for his very valuable Paper. He distinctly remembered and had referred many times since to the Paper, to which the author referred, of Sir Frederick Bramwell's—a Past-President of the Institution—written in 1872. He considered it a monument of skill, and thought that the author's Paper, written so many years afterwards in the epoch-making year of 1901, followed in the same steps. He would be obliged if the author would state what in his experience was the best kind of gland-packing to resist the high temperatures consequent upon high pressures. He would also like to know something about the separators, how he got rid of the oil which must go into the boiler if it was not separated. From the author's remarks he had concluded that he (the author) was entirely in favour of flat slide-valves, and not of piston-valves. He thoroughly agreed with Mr. McLaren's remarks, and was delighted that he had stood up like a man for the old slide-valve, than which there was nothing finer in the whole world. Mr. McLaren had shown that a highly economical triple-expansion engine could be built, fitted with common slide-valves, and so long as they were properly balanced the engine would work and give no trouble.

Mr. Alfred W. Bennis thought it was most difficult to compare the results obtained from boilers on board ship with those obtained on land, because the figures given were always so many pounds of coal used per I.H.P., and there were no means of ascertaining how much steam was used by the main, and how much by the auxiliary engines. Therefore the actual boiler efficiencies were not obtained, and it was impossible to compare them with those of land-boiler trials. The amount of coal burned per square foot of grate in marine work was given in the Paper (page 614) as about 28 lbs. of coal with forced draught. On land that was an average with modern boilers and modern plant, in fact they went up to 35 and 40 lbs. with natural draught. With induced draught and hot air they went up as high as 55 lbs., so that as far as one could see, marine work was a good deal behind land work in such matters.

Mr. Basil Wilson had mentioned mechanical stoking on board ship, and the difficulty which might be experienced when the ship listed. He had had an opportunity, under those conditions, of firing on board ship a machine stoker made by his firm. It was found that although the ship rolled first to one side and then to the other, the coal thrown on was equally balanced. The coal might be thrown more

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on one side at one time than another, but when the ship rolled more would be thrown on the other side, so that practically the balance of an even fire was maintained. Stokers were mentioned in the Paper as having been fitted to some American lake steamers. He had found it impossible to get the machines with which he was connected taken up in England, and had had to go abroad to Spain. The Spaniards were a little ahead of the English in such matters. Most satisfactory results were obtained. Instead of using large Welsh coal, which was very expensive in Barcelona, a native coal costing a great deal less was used, and an increased speed of two knots was obtained from an old cargo boat on which the experiments were made, almost entirely due to the increased production of steam in the boilers. The reduction effected in the coal bill was nearly one third, and the inferior coal was burned without smoke.

Mr. G. D. Hughes quite agreed with the opinions which had been expressed of the great value of the Paper, but there was one very important omission to which he wished to draw attention. The leading ideas in the Paper were confined to the engine power alone, namely, increasing boiler pressure, compounding the engines by increasing the number of cylinders, and similar various matters relating to engines which had been touched upon by the author of the Paper, all tending to increase economy of fuel, the great point aimed at by engineers of the present day. But the author had said nothing about the construction or condition of the boilers; one great invention dealing with the working condition of the boilers was made about half a century ago, which he thought deserved special mention, namely, the introduction of distilled water or surface condensation. If a marine boiler which had been using sea water during the voyage when it got into port was found to have two to six inches or more of salt incrustation, or of muddy deposits as it often was in land boilers, steam could not be made economically, and in addition, the safety and durability of the boilers were very deteriorated and threatened by the overheating and burning of the plates. To remedy this evil, a little over half a century ago Mr. Samuel Hall, of Nottingham, invented the surface condenser which has made ocean navigation practicable, one of the most valuable inventions made in the Nineteenth Century for marine engineering; he (the speaker) had had the opportunity of indicating the very first engine to which the surface condenser had been applied, about the year 1853. This engine, belonging to Mr. W. Gregory, was situated on the borders of a canal at Nottingham, and suffered so seriously from boiler incrustation that the consumption of fuel was very great, and the safety of the boiler was also endangered from overheating of the plates. After the application of the condenser the consumption of fuel was reduced from 9 or 10 lbs. to 3 or 4 lbs. I.H.P. per hour. The vacuum was improved and the incrustation was reduced to nil by using distilled water. He himself was surprised that at almost all the discussions of the Institution, at which he had been present, dealing with naval and ocean engineering, the questions of increased economy, safety, and durability of the boilers from this invention (surface condensation) were almost wholly, if not entirely, ignored or rarely mentioned, and he was surprised to find very few engineers actually knew the name of the author of this most important invention, which they were applying to their engines continually. Mr. Hall introduced his invention to the British Government, but, like some other valuable inventions, it was at first rejected; as it was not patented they, on further consideration, adopted the invention, as he believed every steamship-building nation in the world had done. Mr. Hall was also the inventor of a great improvement in cotton machinery, namely the Gassing engine, which, like the condenser (never being patented), was universally adopted by the trade without any acknowledgment to the inventor. The author of these inventions eventually became reduced in circumstances, and in his latter days, went up to London, when a few engineering friends (members, he believed, of this Institution) brought his case to the notice of the Government; and as a reward for giving the world one of the most important inventions ever made in naval engineering, they voted him a pension of some £100 or £150 per year, and he died in an obscure lodging in London—another instance of unrewarded genius. He felt the name of Mr. Hall deserved some recognition in engineering history, and thought his name might

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fitly be placed among those of Watt, Stephenson, Nasmyth, and other pioneers of engineering science. He (the speaker) would have been glad if the author of the Paper had included amongst the valuable inventions named therein, the surface condenser. However, it was a very valuable contribution, and he had been much gratified and instructed by listening to it.

Mr. HENRY DAVEY, Member of Council, thought the Paper would form one of the most valuable records on marine engineering in the Proceedings of the Institution. To a large extent he agreed with the opinion expressed by the author on steam-jackets for cylinders. The gist of the opinion seemed to be that as the economy of the engine increased because of the use of higher pressure and greater ranges of expansion, the steam-jacket became less necessary. His experience with steam-jackets was, that if one had a very uneconomical engine in itself the jacket might be of very great service. If one had an engine consuming, without the jacket, 30 lbs. of steam per I.H.P. per hour, the jacket would give a very high percentage of economy; but if one had an engine working without the jacket with a consumption as low as the best marine-engines mentioned in the Paper, something like between 11 and 12 lbs. of steam per I.H.P. per hour, then the percentage value of the jacket was very small. He quite agreed with Mr. Donkin's remarks (page 667) that it was more important to put it on the low-pressure cylinder than on the high, but the percentage economy derived from the jacket on such an economical engine was a very small one, probably not more than three or four per cent. When one considered the great extra weight necessary for a jacket on marine-engines, it came to a question of considering whether its application was worth the outlay. He thought that was the view the author had taken of the matter, and that it was a very legitimate view to take.

Mr. W. W. GIRDWOOD said the author had stated in the Paper (page 623) that large cylinders were certainly not desirable. That might have been good advice thirty-six years ago, but it was altogether out of place today. Thirty-six years ago great difficulty had been experienced in making large cylinders, but today they could be as easily made as small ones. There was no difficulty in ensuring cylinder castings sound both inside and out up to 10 feet diameter, and even larger. The author also stated (page 623) that any increase in the number of cranks tended to decrease the vibration. That amounted to saying that they could get a true circle by having as many centres as they pleased. Now, that was the very nucleus around which all future marine engineering must revolve. The torsion strain diagram must be a perfectly straight line—a developed circle; and the best way to get this result was to place the cylinders at 90° and the cranks at 180°. There might be as many cranks as one pleased, but the number must be a multiple of two.

Mr. CHRISTOPHER W. JAMES said that Mr. Basil Wilson (page 673), in referring to the desirability of having a uniform standard factor of safety, had suggested that it would be better to adopt an elastic limit test instead of the ultimate tensile strength test. He would like to know whether Mr. Wilson had ever tried to ascertain accurately the elastic limit of a steel specimen, which was an extremely difficult thing to do. There was a yield point which was often mistaken for the elastic limit, the elastic limit being of course that point at which the constant proportion between the stretch and the load applied ceased, but the yield point was easily perceptible by the drop of the lever of the testing machine. The elastic limit was very variable according to the treatment to which the specimen might have been subjected. It was very easy with a specimen of ordinary mild steel to raise the elastic limit by treatment, such as stretching or cold rolling up to nearly the breaking load, and for that reason, in addition to the extreme difficulty of ascertaining accurately the elastic limit, he thought it would be advisable to continue the present test of the ultimate tensile strength.

Mr. J. F. L. CROSLAND said that amongst the many Tables with which the author's most valuable Paper was filled, the first one had struck him very much. In Table 1 (page 608) the author gave the average results of marine engines for 1872, 1881, 1891 and 1901. The

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rate of progression in economy in marine practice did not appear to be equal to that on land. He noticed that the heating surface per square foot of grate was not given for the year 1872, but for the year 1881 it was 30·4. In 1870 he directed a test upon a triple-expansion engine working at 175 lbs. per square inch, and the coal used per I.H.P. was 1·75. There were no special peculiarities about the engine except its pressure; it had slide-valves. The Table showed that in the year 1881 the heating surface per square foot of grate was 30 with a boiler pressure of 77 lbs. and a coal consumption of 1·83. He was very doubtful whether that test was an accurate one; he did not think the tests generally made at that date were of such a character that one could pin their faith to them; again in the year 1891 a heating surface of 31 feet was given, a boiler pressure of 158·5 and a coal consumption of 1·52 were obtained. Eight years ago he tested at Bolton some Lancashire boilers with Green's economisers working at the same pressure, and the coal consumption was 1·37, which meant 23 I.H.P. for a penny per hour at the then current price of coal 6*s*. per ton. Both results given were better than marine practice. The question arose, "Why were they better?" That question was partly answered by the results of the year 1901. In that year the heating surface had risen to 43 feet per square foot of grate, the boiler pressure was practically 200, and the coal consumption had fallen to 1·48, three-quarters of a pound less than in the year 1872. He thought that the result to a certain extent was due to the increased heating surface. In land practice Green's or some form of economiser had been added to an ordinary boiler which took up the heat of the gases after they left the boiler, the consequence being that nearly another boiler, so far as heating surface was concerned, was added to it, and 50 or 60, and even more, square feet per foot of grate were obtained, and more economy was obtained in the first use of the steam. In the case tested in 1893 to which he referred, the heating surface of the boiler alone was 30·31 to 1, but combined with the economiser it was raised to no less than 73·62 to 1. It seemed to him that a boiler similar to that illustrated by the author on Plate 114, working at 200 lbs. pressure, if it had a Green's economiser connected with it, would be an extremely economical evaporator, and would help to reduce further the extent of fuel per H.P. There was no doubt that something could still be done in that connection, and he believed the author on further consideration would see that one of the steps in the way of economy lay in that direction. Dealing with the question of power, if they were to use boilers similar to that shown on Plate 114, the question of strength had to be taken into consideration. The author in another of his admirable Tables gave the stresses on stays and the factors of safety for boilers, the Board of Trade rule being 4·5 and the Admiralty 3·9 (page 613). He was under the impression that in the instructions to surveyors the factor of safety was 5. He would like to know if that had been altered.

Mr. McKechnie said it had been reduced recently in one special case.

Mr. Crosland said the rule he had adopted during the whole of his practice was 4, which he thought was sufficient for all practical purposes. He had never had any injury or accident to a boiler which had been made with that factor of safety. He entirely agreed with Mr. Wilson (page 674) that it was only portions of boilers which seriously suffered. One never heard of a boiler explosion which occurred from any part which was not liable to corrosion or some special form of injury. In practice many boilers worked safely with even a lower factor than 4, and in view of the fact that great improvements in material were constantly being made, such as nickel steel, lighter scantlings and reduced weights might be adopted, a higher pressure would probably result in some further increase in economy. He had always held that it was not worth while to use quadruple expansion on less than 250 lbs. pressure. He noticed that the author put the figure at 220, so that practically they were nearly agreed. With regard to low-pressure cylinders of triple and quadruple engines, it was much more convenient to use two cylinders instead of one enormous cylinder which had such a large diameter of piston, and was practically unmanageable. Therefore, for the sake of convenience in building engines, it was probably better to use two

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low-pressure cylinders in connection with the high pressure and intermediate. Unless one was dealing with 250 lbs. pressure, he was quite clear there was no advantage from quadruple expansion. He had been interested with the question of triple expansion throughout the whole of his working life. On the questions of valves, most of the engines on land which worked economically used the Corliss valve. He did not know that any serious attempt had ever been made to try that valve in marine practice. But on land Messrs. James Simpson and Co., of Pimlico, have since 1883 driven Corliss gear positively, arranging the exhaust valve of a compound beam pumping-engine with a low-pressure cylinder of 51 inches diameter and 9 feet stroke in that manner. In many cases where they have replaced cylinders of old beam engines, they have adopted positively driven Corliss gear with excellent results. There did not seem to be any reason why Corliss valves could not be adopted in marine practice, and good results should follow, as these valves were very much easier to handle than flat slides or even piston valves. The firm referred to fitted separate Corliss-valve liners, which could be accurately machined. He did not see why it should not be given a fair trial, and a firm like Messrs. Vickers, Sons and Maxim, with gentlemen of the extremely energetic and go-ahead kind that their works showed, might build such an engine and have it carefully tested. He did not think they should be baulked by any fear of results pointed out by Mr. Wilson, because engines could be tried for economy without going to sea. Any conditions which arose afterwards through the motion of the water would remain the same, whatever the style of the engine was. A vessel might be fixed, and the boilers and engines work in those circumstances, exhaustive and careful economical trials being made similar to those on land.

The question of mechanical firing was very seldom touched upon. It seemed to him that mechanical firing was of vast importance on board ship. Anybody who had seen the dreadful sufferings of the stokers, even on the finest liners, like the "Majestic" and the "Teutonic," would feel anxious that some form of mechanical stoker should be introduced. Attention had been given to the subject by many engineers—in fact, he assisted his father in trying to work out mechanical firing as far back as the year 1859, and it was quite possible that the apparatus they made at that time would be equally applicable at the present time. It was a modification of the jacket grate, combined with a system of carrying the coal direct from the bunkers by a form of conveyor to hoppers, and then delivering it in a crushed form to the grate. Men could not be dispensed with altogether, but all the extremely rough, hard, and painful labour which the poor stokers now had to undergo would be got rid of. In his opinion there was no very serious difficulty in making a mechanical stoker, provided the subject was taken up by such an eminent firm as the Naval Construction Company. Two or three gentlemen not very far from him could evolve an arrangement which would be perfectly satisfactory. It was within the abilities of many men present, and he hoped the next time the Institution met, a large and forward step in that direction would have been made.

Sir Hiram S. Maxim said he had been very much amused and interested by the author's admirable Paper. It was the ablest Paper he had read on marine engineering: in fact the Paper and the discussion reminded him very strongly of the time when he was a young engineer and draughtsman in the early "seventies." He was then at the largest marine engineering works in America, the Novelty Ironworks. Wooden ships of 5,000 tons, with cylinders 105 inches in diameter, and strokes of 12 or 15 feet, were built there. The vessels were side-wheelers, the wheels being 12 feet face with a diameter of 42 feet. The engines developed sufficient power to give a speed of from 14 to 16 knots an hour, and the ships were supposed at that time to be the fastest of their class in the world. In order that one might understand the great progress which had been made in marine engineering during the last half century, he would point out that the first book he studied on marine engineering was "Bourne's Engineering." That was considered a very good work at the time. It gave the formula for finding out the H.P. of an engine, called "The Admiralty formula," which was very simple. One multiplied the square of the diameter of the cylinder by a certain co-efficient which was given. Nothing else had to be done. The piston speed was constant—250 feet a minute; the pressure of the steam was 12 lbs. per square inch, and it was supposed there would be a vacuum of 27 inches. Consequently, as all those things were quite constant and uniform for all sizes of ships the formula was very simple indeed.

With regard to the Corliss valve-gear, many years ago there was an exhibition of engines at Brussels, and all the best engines had that valve-gear. Corliss himself did not exhibit, but he obtained the Grand Prize. He went to an Exhibition many years ago in Vienna where a large number of beautiful engines were on exhibition, and every one of them had the Corliss valve-gear. On the Continent of Europe a great deal more attention was paid to economy in fuel than in England, because coal was dear there as compared with England. He thought it would be found in French land-engineering that the heating surface was considerably more in proportion to the H.P. developed than it was in England or in the United States of America. At the Paris Exhibition last year he examined a great number of large engines, and every one of them, with a single exception, had the Corliss valve-gear. Mr. Yerkes, who had done so much in the United States of America, was in England at the present moment. He had a very clever Western American engineer with him; what was called in England "a practical man." He did not care much for theory; he wanted an engine that would run. That gentleman told him that he had had experience with a great number of valves in the States, and he found that slide valves and gridiron valves not only cut but rocked, thereby causing a leakage of a good deal of steam, but he had never had any trouble whatsoever with the Corliss valve-gear. The question had been asked as to whether a Corliss engine had ever been put on a steamer. He believed it had. A steamer was built in New York with a Corliss engine, geared by a cast-iron gear on to a wooden pinion driving a screw propeller, but there was so much machinery to it, and the engine was so high up in the ship, that he did not believe any more were ever built. Personally he was much in favour of the

Corliss valve-gear, but he did not know whether it could be used on board a ship. A very clever and thorough-going engineer, a Professor in the Cornell University, made an engine without any packing in it anywhere. He employed a species of a square piston-valve. One of these engines ran for several years in the great workshops of Messrs. Pratt and Whitney, who, he thought the members would admit, were very good mechanics; and Mr. Pratt told him that it was a comfort to have such an engine, as he had never had the least trouble with it. It was a peculiar form of valve-gear, but it was almost as economical as the Corliss. The engine required remarkably fine fitting, and it was almost impractical to make an engine so accurately as it was made; all the parts were extremely heavy and well fitted. Some years ago a firm in the States introduced a cheap engine which had two eccentrics, one on each side of the cylinder. One simply worked the exhaust, and had the conventional amount of advance. On the other side there was a gridiron valve with three ports worked by an eccentric which travelled directly across the shaft. It might be said that if one continued the travel the engine would be reversed, but it only travelled a little past the centre. As the eccentric moved towards mid-gear, it increased the angle of advance; it cut the steam off earlier in the stroke, the lap and the lead remained constant. As the exhaust was worked by a separate eccentric, it was not distorted in the least. That engine produced almost as good results as the Corliss gear, and every part of it was extremely durable. He did not know how many of the engines were made, but he understood that they were now being manufactured in large quantities. On the Continent of Europe the Corliss valve-gear was infinitely more popular than in England; it was liked better in the United States than in England, but was not so popular as it was on the Continent. He thought it would be found that the Corliss valve-gear was used least of all by England. A good many Americans were in favour of a very durable valve-gear, one that was easily made, which could be attained sometimes by the use of piston-valves or, better still, by the kind of valve to which he had referred. He had been much interested in the discussion, which had been very instructive to him. He did not pretend to be an up-to-date steam-engineer, but everything relating to such work was extremely interesting to him.

Mr. E. B. ELLINGTON, Member of Council, said he rose in consequence of a remark made by the last speaker. Between thirty and forty years ago he was engaged in marine-engineering work and was in the habit of using many of the Admiralty formulæ, which were a source of great amusement to the gentlemen in the drawing-office at the time. It was quite well understood, even at that early stage in marine engineering, that they were simple empirical formulæ which settled the size of an engine and nothing else. To his mind the most remarkable thing about the Paper was the very small amount of progress made in the economy of steam-engines since the "sixties." He remembered the initial stages of the great revolutions which took place then, the introduction of high-pressure steam, the compounding of engines, the use of surface condensers, and superheating. The engines were constructed of great power, and consumed about 2 or 2¼ lbs. of coal per I.H.P. per hour. In the thirty or forty years which had elapsed since that time the figure had only been reduced to 1½ lbs. and in some exceptional cases to 1¼ lbs. It would be noticed that the principal difference in the consumption of coal for a given quantity of work done was due to the increase of the size of the steamers. It would be found that from a scientific standpoint the steam-engine in 1870 was equally as perfect as it was today. The steam economy which had been realised had been due almost entirely to the increase of steam pressures. The increase of steam pressures had necessitated the adoption of compounding to a greater extent, but the more one looked at it the more it would be seen that the greatest economy which had been attained was due to the improved methods of manufacture, to the improved materials, and to the means of carrying out the demands which were made for higher pressures. Another striking subject connected with the Paper was the enormous difference between marine work for the Mercantile Marine and for Naval purposes. The boilers were now probably as perfect as they could be made, and yet the great question of water-tube *versus* Scotch or cylindrical boilers remained unsettled. It seemed to him that that question could not be determined simply upon the basis of which was the best boiler. Information was required as to which was the best boiler for the particular purpose for which it had to be used, and this involved questions of a far-reaching character. His remarks had been directed towards upholding the character of the work done by their predecessors. He would also like the author to tell them how it was that the superheating to which he referred as being used in the "sixties" was abandoned a few years afterwards?

Mr. Henry A. Ivatt, Member of Council, assured the author of his great appreciation of the Paper. He would like to know what metal the piston-valves were made of which had no rings or packing, because the results obtained from piston-valves depended largely on the material of which the valves and faces were made. He had been extremely interested in Mr. McLaren's remarks about balanced slide-valves (page 669); he had several valves running on the Great Northern Railway balanced on Richardson's system of four strips in the back of the valve, like an Oxford frame. Some of these valves were running in the 8-feet engines, built by the late Mr. Stirling, giving very good results. He had one pair running on an inside-cylinder engine where there was not much room to get in the plate and valves, but they were doing very well. He also used the same description of balanced valves in his ten-wheel express engines, which have outside cylinders, four coupled wheels under the boiler, a leading bogie, and a pair of carrying wheels under the fire-box; the valves worked against a vertical face having two ports only, the back of the valve being open inside the balancing strips, so allowing the exhaust to go straight through to the blast-pipe without any bend or obstruction; and on the face of the cylinder instead of there being three parts there were only two. The exhaust went through the back of the valve and straight up the chimney. He used that kind of valve with success.

Mr. W. Silver Hall wished to offer one remark with regard to the possibilities of applying Corliss valves to marine engines. No doubt there were many engineers present who were thoroughly conversant with the practice and the use of the Corliss engines, more so than he was himself, but he believed it would be found there was a certain limitation of the speed. The Corliss engine could be run at only a certain number of revolutions, and when that speed was exceeded the valves would not close quick enough without springs or some artificial means at the back. That limitation in speed, which he believed actually existed, would hinder the application of the Corliss valve-gear to the speeds required for marine engines. That might or might not be the case.

Mr. McKechnie, in reply, thanked the members for the patience with which they had listened to his Paper and for the interest they had taken in it. It had led to a very valuable discussion, and thus his principal object in writing the Paper had been fulfilled. As time was short he would prefer to reply in writing to many of the remarks made. He would only refer now to one or two points: first with respect to the equilibrium rings, he had been greatly interested in the remarks of Mr. McLaren, who seemed to have proceeded very much on the same lines as those connected with marine engineering were following out. His firm did not adopt flat slide-valves for all cylinders; they fitted piston valves for the high pressure and the intermediate, using a flat valve for the low pressure with a thoroughly balanced slide and an equilibrium ring very similar to the one he had described. With very high pressures in the high-pressure and intermediate cylinders, flat slide-valves might give a certain amount of trouble, and any leakage from piston valves was always trapped in the low-pressure receiver and was prevented from going into the condenser by the low-pressure flat valve. In the trial of the "Amphitrite," which was built by the Vickers Company, a gauge was fitted in connection with the low-pressure receiver. There was a gauge on the back of the valve, which was in direct communication with the condenser, and another gauge on the receiver itself, and it was found that while there was a pressure of about 25 lbs. in the receiver there was a vacuum of several inches inside the valve casing. That showed that the system of ring which had been adopted gave every satisfaction. Only the low-pressure jackets were used in the case of the "Amphitrite," and if he remembered rightly that boat had the lowest recorded coal consumption per unit of power. He always found that there was a certain amount of leakage from the drain valves on jackets. He gave instructions to keep only about 10 lbs. pressure upon the low-pressure jacket.

He thanked the members for the hearty vote of thanks which had been so kindly accorded to him.

Communications.

M. le Professeur SAUVAGE, in continuation of his remarks at the meeting (page 668), wrote that, regarding what had been said by Mr. Hughes (page 679), he would like to add that among French engineers Samuel Hall's merits were duly recognised. Hall's condenser was mentioned in many publications on the subject of marine engines. A few years ago the writer published a treatise and reproduced in it some old tracings of Hall's condenser; he thought they were very interesting, as they were so much like what was done nowadays, and he found it difficult to understand how such a capital invention had been allowed to lapse for such a long period.

Mr. MCKECHNIE wrote, in continuation of his remarks at the Meeting, that in replying to the discussion at greater length than was possible on the day on which the Paper was read at the Summer Meeting in Barrow-in-Furness, owing to the short time available and to the importance of not interfering with the arrangements for visits to works, he would like to thank again the Members and those who spoke upon the Paper for their appreciation of his contribution to the Proceedings—an appreciation which was especially recognisable in the value of the discussion. Many points worthy of the close consideration of engineers had been raised by several of the speakers; but it was not desirable that he should here

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refer to all of them. One or two of the speakers, notably Mr. Bryan Donkin and Professor Sauvage, expressed the desire that one or two of the subjects touched upon in the Paper should have been dealt with in more detail, but such a review as had been attempted in the Paper, being comprehensive, prevented any one item in marine engineering progress from being discussed in minute detail, more particularly as in several instances such matters had been dealt with in separate memoirs, references to which were given in the Paper. Thus, as regards the subject of forced lubrication raised by Professor Sauvage in his most interesting remarks (page 669), this question was so fully dealt with by Mr. Alfred Morcom,* as mentioned (page 634), that "it is not necessary here to do further than to indicate progress."

Again, with reference to the efficiency of using steam in the jackets, this matter was fully discussed in the Paper read by Sir John Durston, K.C.B., the Engineer-in-Chief of the Navy,† as mentioned (page 626). This contribution gave most valuable data on this question, and he did not deem it necessary to do further than refer to the general results obtained. The engines of H.M.S. "Argonaut," he might now add, were jacketed on the cylinder barrels only, and the long series of trials embraced tests with the low-pressure jackets as well as with all the jackets using steam. The pressure of steam in the low-pressure jackets was about 20 lbs. above that in the receivers, as was also the case with the intermediate; but as regards the high-pressure jacket the steam pressure was not so high, and it was shown that at full power there was an increase of water consumption per H.P. hour of 5·8 per cent. when the jackets were in use, and at three-fourths power of 2·6 per cent., but at low power the increase was only 0·06 lb., or less than ½ per cent., the general conclusion being that "at the higher powers the tests seemed to show that no gain in economy is attained by steam-jacketing as carried out in this vessel." Again, in regard to the measurement of the vibration of the "Deutschland," the full particulars were given in the Paper read by Herr Otto Schlick at the Spring Meeting of the Institution of Naval Architects last year.*

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* Proceedings 1897, page 316.

† Transactions, Institution of Naval Architects, 1899, vol. xli, page 1.

As regards the question of the re-heating or drying of steam, also raised by Mr. Bryan Donkin (page 667), it might be noted that the system had been used at sea, notably in a Russian paddle-steamer having compound engines constructed by Messrs. Hawthorn, Leslie and Co. about 1893, but he had no data as to the results. In reply to the same speaker's question as to the method of fixing jackets, this was done by means of an internal flange on the liner secured by pins to the cylinder bottom. Professor Sauvage seemed to anticipate difficulty in applying a system of superheating steam with cylindrical boilers, but the author could not see that there should be any such difficulty; he understood that in addition to the case quoted in the Paper there had been an installation of the Schmidt superheater fitted to one of the large North German Lloyd steamers, and in this case also the results of sea steaming would be awaited with great interest by all engineers. Mr. Ellington (page 689) raised the question as to why superheating, when tried in the "sixties," was not continued. He himself believed the cause was the absence of a suitable lubricant to stand the high temperature attained in high-pressure cylinders; mineral oils were not then in general use.

The question of piston and flat slide-valves had naturally occupied a considerable part of the discussion, and it was interesting to note the diversity of opinion prevailing, but it was probably not desirable to enter further into the question. There was no doubt that varying circumstances would affect the question of choice, and it would be a mistake to lay down any fixed rule; but, as he had already indicated, he favoured the piston valve for the high-pressure and intermediate cylinders and the slide-valve for low-pressure cylinders. His object in dealing with the question of relief rings was not so much to establish superiority for the flat valves as to show that, where considered desirable, they could be as satisfactorily

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* Transactions, Institution of Naval Architects, 1900, vol. xlii, page 135.

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balanced as those of the piston type. He could not agree with Professor Sauvage that the piston-valve should be as much applied even to the low-pressure cylinder as it was to the high and intermediate cylinders, nor could he accept Mr. McLaren's suggestion (page 672) that the flat valve should be always adopted. No doubt Mr. McLaren had attained most satisfactory results in electric lighting engines, but in marine practice there were other conditions which must be taken note of in determining the questions of design—a difference in requirement which was at times lost sight of by several speakers. In dealing with valves, a reference might be made to the remarks of Sir Hiram Maxim and Mr. W. Silver Hall, both of whom advocated the trial of Corliss valve gear in marine engines. Certainly for slow-speed engines this type of gear had given very satisfactory results, and it was, as Sir Hiram Maxim suggested (page 687), somewhat surprising that it was not more extensively applied; but in the case of high-speed engines whose number of revolutions exceeded 110 or 120 per minute, the inertia of the trip gear would tend to abnormal wear, and result in a loss of economy. Corliss gears, as suggested by Mr. Crosland (page 684), had been tried at sea. In addition to the examples mentioned by Sir Hiram Maxim, the Corliss system had been applied to two Atlantic steamers by Palmers Co.; but the simplicity of design and of working of ordinary link motion with the slide or piston valve would probably cause it to be retained. Mr. Basil Wilson (page 676) advocated that improvement seemed possible in the direction of drier steam and less clearance spaces and surfaces; while these were undoubtedly aids to economy, it should not be forgotten that comfortable clearance volumes properly filled by compression were not opposed to economy, and tended at the same time to produce a much quieter running engine than did the 1½ to 4 per cent. clearances sought after in American stationary engine practice.

The importance given during the discussion to the question of the factor of safety in boilers, and the diversity of opinion expressed, justified in large measure the plea he had made for some action towards securing greater uniformity in the standard tests of boilers and of boiler materials, and he hoped that the subject might not be lost sight of. There was much to be said in favour of Mr. Wilson's contention that the factor should be determined on elastic limit, but it was of importance, as suggested by Mr. C. W. James (page 681), that this elastic limit should be clearly defined, because it was a somewhat indefinite quantity. The true scientific criterion was the elastic range, and not merely the elastic limit in tension, which latter might be anything an experimenter liked to make it by suitable treatment of the material. It was certainly satisfactory that an engineer, having such experience of merchant ship work as was possessed by Mr. Wilson, should agree in advocating some means for the reduction of the weight of boilers; and the point he had raised, in favour of the factor of safety of such parts of boilers as were not subject to much wear being reduced in comparison with the remainder of the structure, was of great importance. Mr. Crosland (page 683) asked about the Board of Trade rule as to the factor of safety; he would find in the present edition of the Rules on page 50, that a factor of safety of 4·5 was permitted under certain conditions as to material, design and workmanship.

Mr. Wilson referred to the question of mechanical stoking at sea, and especially to difficulties to be met with. The knowledge of these difficulties should not adversely influence effort towards overcoming them, and he was convinced that in the near future they would be overcome. There was nothing impossible about such an application of mechanism, and indeed the trials at sea, as mentioned by one or two speakers, had proved that a marine stoker was not an impossibility. There could be no doubt that when a satisfactory design was presented, it would be appreciated not only for its economy, but for the improved condition which it would bring about in the stoke-hole, although, he should add, that the picture painted by some of the speakers as to the physical conditions of the stoker were rather highly coloured. Full details of the trials of the mechanical stoker in American waters, which was referred to in the Paper (page 616), would be found in the Journal of the American Society of Naval Engineers, vol. xii, No. 4, page 895.

In answer to Mr. A. Tannett-Walker (page 677), the author's experience was in favour of a floating metallic packing for glands

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where the temperatures were high. As regards separators for getting rid of the oil from the feed-water—a point raised by the same speaker—he might state that the usual method in marine practice was to have double or treble filtration over ample areas of blanket, Turkish towelling, or matting; a Laval cream separator had been successfully used in the Bristol Electric Power Station. These methods attacked the feed when in the form of water, the filters being placed either in the suction or discharge side of the feed pump. No method of preventing oil from getting into the condenser seemed to have been successful, at least so far as the exhaust from ship-propelling engines was concerned. Mr. G. D. Hughes (page 679) claimed recognition on the part of Samuel Hall, of Nottingham, for the invention of the surface condenser, and complained that this had been lost sight of in the Paper, but an event of 1853 could scarcely come within the scope of a "Review of Marine Engineering during the last Ten Years." Professor Ewing had recently quoted a still earlier date for the surface condenser than that mentioned by Mr. Hughes, stating that it was introduced into marine practice in 1831, although it did not then attain the success which encouraged wide application. Honour was no doubt due to Samuel Hall for making a practical success of this indispensable aid to successful marine engines, but it should not be forgotten that James Watt, in his first experiment on the use of a condensing apparatus separate from the engine cylinder, used a surface condenser; and the model, still in existence, combined all the essential parts of the modern marine surface condenser. This dated from some time between 1763 and 1769.

Mr. J. F. L. Crosland (page 682) compared some coal consumption results with those in Table I, (page 608), but omitted to recognise that those in the Table were average results and were not got from special engines or tests. The particulars for previous decades were taken from the results given in former Papers to this Institution referred to on page 607. He claimed that the land performances which he quoted were due to the greater ratio of heating surface to grate area, especially where economisers were used. This contention had long been recognised by marine engineers.

Experience had, however, shown that when the heating surface was carried beyond a certain value the increase of economy was not sufficient to counterbalance the extra weight carried. Economisers or waste heat feed-heaters have been tried in the past, and quite recently in the case of Belleville boilers. On board ship, however, they have always had to be placed in a rather uncomfortable position, and from weight considerations have always been constructed of wrought-iron or steel tubes, instead of being of cast-iron pipes, which answered so well in land practice. Consequently corrosion, internal and external, had been a source of trouble. Possibly in time a well-considered system of warming the feed, before it reached the economiser (to prevent external condensation from the gases) and a rigid exclusion or extraction of air from the feed by contact heaters or otherwise, would enable a workable system to be evolved; undoubtedly additional heating surface in an economiser containing feed-water was much more effective than the same amount of additional surface would be in a boiler, when once a certain ratio of heating surface to grate area had been attained in the boiler. An ideal system might employ the waste gases nearest the boiler in a superheater, pass them on from there to an economiser, which would receive its feed already partly heated by contact heaters utilising steam from the low-pressure chests, finally passing on the gases for further cooling to a system such as the Howden or Ellis and Eaves to heat the incoming furnace air-supply. This application of a partly regenerative method to both engine and boiler would represent the high-water mark of economy; but when all was said, a steamship was not an ideal place to apply it, where light weight, reasonable space occupied, and absence of complication was just as important a factor as a problematic gain of efficiency.

In reply to Mr. Ivatt (page 689), he might state that the piston valves which had no spring ring were made of cast-iron and worked in a hard cast-iron liner.

SOME WORK IN THE DEVELOPMENT OF A MOTOR-CAR.

By Mr. M. HOLROYD SMITH, *Member*, of London.

That motor-cars have passed the experimental stage is generally admitted, but those who have had any practical experience, either in the construction or running of motor-cars, will also admit that there is ample room for improvement; and perhaps there is no other mechanical subject at the present time occupying the serious attention of a larger number of engineers.

It is not intended in this Paper to make a compilation of the world's work generally; that has been ably done by others. Nor will the author attempt to give a full and complete account of his own experimental researches, though some of them might be useful in showing others what not to do, and so help them to avoid a repetition of errors.

This Paper will for the sake of brevity be confined as far as possible to a description of the work involved in the construction of the latest Petrol car designed and built by the author, Plate 133, and to deductions therefrom. It may be necessary at times to refer to first principles and to discuss some points theoretically.

It is to be regretted that many motor vehicles produced by English makers consist of numerous parts collected mostly from France and assembled together here. From a business standpoint this may have been a prudent course to adopt, but it is hardly creditable to the English engineering profession.

The author's first essay was to construct a heavy-oil engine, but he came to the conclusion that the supposed additional safety in using heavy oil was a fallacy, inasmuch as heating the oil to vaporise it involves a greater risk of setting fire to the car than is likely to result from the use of petrol gasifying at or little above atmospheric temperature, especially when tube ignition is abandoned in favour of electric ignition.

It may seem hardly necessary to state that the petrol motor is constructed on the Otto cycle of suction, compression, explosion, and exhaust. The four phases have become so general that it is to be feared their full meaning is sometimes forgotten, and yet they are the cardinal points in the design of a Petrol motor. The induction valve must permit the charge to be drawn in freely, and yet close with sufficient precision to prevent any escape on the return stroke. The compression should be adjustable so as to arrive at the best results with the mixture obtainable, and for the impulse to be most effective the mixture must be fully ignited at the right time. Then comes the not easy problem of how to discharge quietly the spent gases without putting undue back-pressure on the piston.

It is hardly likely that anyone conversant with the subject would venture to assert that perfection had been attained in each and all of these four elementary conditions combined. Like most other things it becomes a question of compromise, and the designer has also to consider the practical items of accessibility, strength, weight, space occupied, cooling, lubrication, protection of working parts from road dust, etc., and in new work these have again to be qualified by the difficulty in finding mechanicians expert enough to carry out thoroughly well something in which they have had little or no previous experience. The determination to avoid copying French designs, using parts made abroad, or employing foreign workmen, may be given as explaining the prolonged time the author's work has occupied. For any work to be successful not only must the general principles and arrangement be sound, but the smallest details must be carefully and accurately carried out.

If the general arrangement or scheme be wrong, no amount of accuracy in executing the details will make the work a success. On the other hand, no matter how good the design or sound the theory, the whole may be spoilt by some trifling defect in an apparently insignificant detail. For example, in an early car the engine, varying speed, reversing and differential gearing, were all arranged directly on the driving axle, the object being that by removing the driving axle all the mechanism would come out with it. The arrangement failed in spite of the good work put into it, because the engine could not stand the racket, having only the rubber tyres on the wheels to deaden the shocks when running over rough roads. If all roads were newly-laid Val de Travers asphalte or wood pavement the arrangement would have worked well.

On the other hand, with the best engine made, a slight flaw in an ignition tube, a bent valve-stem, a leaky joint, or some other trifling imperfection, and it will not work. For the reasons given above, not only the general design but several minor parts of the author's engine will be described in detail.

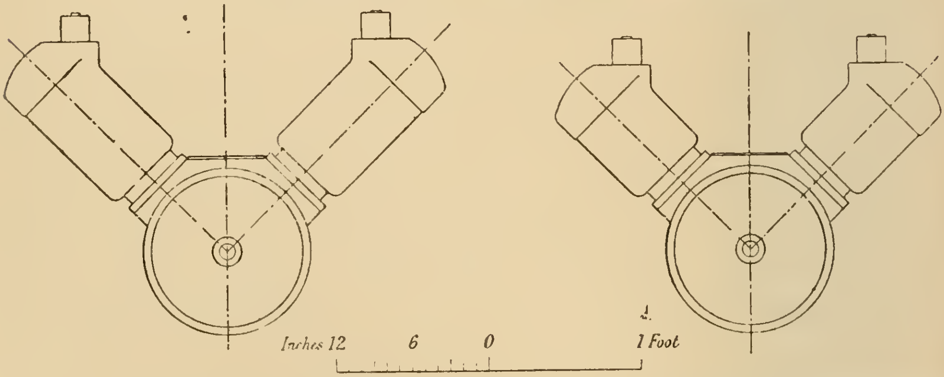
The Engine.—The engine may be described as a diagonal engine, that is, two cylinders are placed at an angle of 90° to each other, both in the same vertical plane.

Plate 129 shows the general arrangement giving respectively end elevation, side elevation, plan, and sectional plan of the crank chamber. The cylinders rest upon an enclosed base forming the crank chamber; they are at right angles to each other in order to minimise vibration, a single crank being used; the balance weights upon the crank are equal to the weight of one piston and one connecting-rod only (not to two), the consequence being that when one piston is at the part of the stroke where it needs no balancing, the centrifugal force of the balance weights, which would in engines as usually arranged produce a side shake, is then required to balance the piston of the other cylinder. Though this arrangement does not compensate for the unequal effect of the connecting-rods, it is sufficiently satisfactory for all practical purposes.

Objection may be made to placing the cylinders at right angles to each other, because the arrangement requires a wide spread. It is therefore desirable to keep the cylinders as short as possible, and in order to accomplish this without using too short a connecting-rod or lessening the number of piston rings, the construction shown in Fig. 5, Plate 130, was adopted, namely, the pistons are made composite, that is to say they consist of a piston within a piston.

The outer one, T, being the piston proper provided with packing rings R, the inner piston I, fixed by screwing or otherwise into the outer one, carries the hollow pin O, upon which works the top end of the connecting-rod. This arrangement not only permits the cylinder to be made shorter, but more packing rings can be employed, and gives facility for adjusting the capacity of the combustion chamber and thus varying the compression, by simply screwing the inner piston further in or out of the piston proper. The two can be locked at any half-turn by means of the key K, Fig. 6, which is an easy fit in the key-ways provided for it, and is retained in position by having a spring extension, provided with a pin that enters a hole H in the side of the piston; this arrangement is found to work well in practice, no lock-nuts are required and it does not work loose.

Fig. 8.—*Comparison of ordinary and adjustable Pistons.*



The saving in length of cylinders and therefore weight and "spread" of engine is shown in Fig. 8.

In order to keep both cylinders in the same transverse vertical plane and to enable both to act with equal directness on the same crank-pin, the connecting-rods are made as shown in Figs. 5 and 7. The base E of one rod embraces the full length of the crank-pin, the base E^1 of the second overlaps the first and acts through it. Serious damage might result from the nuts that secure the caps of the connecting-rods working loose, and as usually constructed their adjustment and locking is a difficult and uncertain operation. To overcome this the caps are at one side hinged to their respective connecting-rods at J, and carry at their other sides a bolt L hinged to the cap at M. This bolt is, when loose, free to swing in or out of the fork-shaped projection G on the end of the connecting-rod, and the bolt has attached to it the spring Q that will enter with the bolt between the forked projection G and engage with the serrated or notched edge of the washer or shoulder forming part of the nut N, and so prevent it from turning. This nut is operated by a box-spanner, the outer edge of which when applied forces out the spring catch Q, releasing the notched collar and permitting the nut to be turned; when the box-spanner is removed the spring catch returns and engages with the notches in the collar, thus automatically locking the nut.

Valves.—The induction valves V, Plate 129, stand vertically on the cylinder, and are bolted thereto in such a manner that the flanges may be turned to face right or left inwards or outwards as may be most convenient for coupling to the carburettor. The diameter of these valves relative to the diameter of the piston is proportionally larger than recognised practice, the object being to reduce the lift of the valve and so permit a quick return. For it is found that a heavy valve with a long lift does not reciprocate fast enough to keep time with the engine when running at a high velocity, and practically acts as a limitation to the speed, because if the valve gets out of step with the piston, then either faulty compression or back-firing into the carburettor chamber will occur. To avoid attenuation of the supply charge, there must be as little restriction as possible to the suction, the tension of the spring controlling the valve must therefore be adjustable. The idea that naturally suggests itself is to screw the valve spindle and use lock-nuts, but practice shows that these lock-nuts give trouble; a large diameter spring is therefore used, and numerous holes at right angles to each other are drilled through the upper part of the spindle into which the bent top end of the spring can be inserted, thus dispensing with the extra weight and trouble of lock-nuts. The induction-valve spring may also be adjusted in the manner hereafter described in connection with the carburettor, which provides delicacy of adjustment without any risk of shaking loose.

The exhaust-valve boxes are also separate from the cylinder; here again comes the question of compromise, if cast with the cylinders there would be apparently less work and weight, and a troublesome water joint would be avoided; but, on the other hand, there would be greater difficulty in getting a sound casting. The coring would be troublesome, and any error in boring the valve seat or gland would make the whole cylinder a waster, and there would be no possibility of renewal. The author has been informed by another engineer who also has devoted himself to experimental work, that, in one engine he constructed, twenty castings had to be supplied before he succeeded in getting one that was satisfactory. Renewability of parts is therefore a thing to be desired.

As the exhaust valve is subject to the fierce heat of the explosion, and of the escaping gases, it is desirable not only that the valve box should be water-jacketed, but that there should be ready access thereto for examination, adjustment, regrinding, and renewal. To accomplish this the design shown in Figs. 9 and 10, Plate 130, has been adopted.

It will be seen that the valve and spindle can be readily withdrawn through the circular hole *a*. This hole is closed by the cup *b* making a ground joint; the cup is held in position by the set-screw *c* which passes through the cap *d*. The cap is provided with wings *e* that engage with what may be conveniently described as the bayonet grooves *f* formed on the surface of the valve box. When the set-screw is slackened and the cup is given a quarter-turn, it can be at once removed and the cup lifted, permitting access to the valve box. This not only facilitates the removal or regrinding of the valve, but is very useful when setting the valve. It is hardly necessary here to enlarge upon the important part that the correct setting of the exhaust valve plays in the good working of an impulse engine.

Cam Shaft.—The drum-shaped base forming the crank chamber has one end D, Plate 129, cast with it and carrying one of the bearings A of the crank shaft S. The other end of the crank shaft is carried in the bearing B forming part of the fixing F, the base of which is turned to fit correctly and rest upon the inner surface of the crank chamber to which it is bolted. The removable fixing also carries the gear wheels, shafts, and cams that operate the exhaust valves, which are driven by the pinion P on the crank shaft S.

The whole of this operating mechanism can therefore be withdrawn complete with the fixing F from the crank chamber. When it is in position, it is securely protected by the removable end cover C which closes the open end of the crank chamber, making it oil-tight; it can, however, be easily removed to permit examination of the cam wheels and other parts within the chamber. Access is also gained to the crank chamber through the hand holes top and bottom. The lid of the upper one is constructed to permit air breathing, and so avoid a compression in the crank chamber, which forces the oil out through the bearings and joints. It is found in practice that the dash of the crank and the fling of the balance weights makes such a distribution of oil that the cylinders, gear-wheels, and all bearings are efficiently lubricated.

The crank shaft is reduced in diameter and extended through a simple stuffing-box in the drum cover, and drives directly, without the intermission of belt or gearing, a centrifugal pump for circulating the cooling water.

The other end of the crank shaft carries the fly-wheel and transmits the power through a suitable coupling to the axle of the car, in a manner to be afterwards described.

The two half-speed cam shafts 1, 2, are also extended through the cover of the crank chamber, one carrying the commutator for timing the electric ignition and one actuating an air-pump for governing the speed of the engine. The operation is as follows:—

Pneumatic Governing.—The air-pump is provided with inlet and outlet valves, and from the outlet a pipe conveys the air to a drum U, Fig. 9, Plate 130, thence to the second drum U^1, to the outlet of which a pipe is attached and carried to a position within easy reach of the driver. The end of the pipe is fitted with a valve adjustable to any degree between fully open or actually closed. The drums are fitted with diaphragms, links, and trip levers, restrained by adjustable springs as shown in Fig. 9. When air is pumped into the drums and the outlet restricted, the pressure on the diaphragms overcomes the tension of the springs, and the trip levers are pushed forward, engaging with the collars *g* on the exhaust-valve spindles, thus retaining them open and preventing any suction through the induction valve at the next downward stroke of the piston. The tension springs are preferably adjusted so that one shall be a little weaker than the other, permitting its exhaust valve to be operated first, and so shutting off one cylinder before the other.

By adjusting the valve at the end of the escape pipe near the driver, the speed can be regulated as desired, or the engine stopped altogether. It simply becomes a question of the relative rate of inflow of air to the drums from the pump, and the outflow from the drums through the escape pipe.

Whether it is better to govern by holding the exhaust open after a discharge or neglecting to open it, keeping the spent gases within the cylinder, will not now be discussed; but the opinion may be expressed that either of these alternatives is more economical than governing by varying the quality of the mixture, or the time of firing.

The advantage claimed for the system of pneumatic governing described *versus* control by centrifugal or inertia governors are less likelihood of derangement, coupled with a wide range of speed easily adjustable at the will of the driver.

Carburettor.—So much for the mechanical part of the engine. We have now to consider what may be termed the scientific part, namely, the gasifying of the petrol and making the proper mixture. That this is a matter of considerable difficulty as well as importance is evidenced by the numerous and varied devices of carburettors that have been and are still being produced; the type most generally adopted requires a float feed, but owing to the attempt now being made to monopolise the use of the float, the one designed and used by the author before the crusade commenced will be described. In it an attempt is made to regulate automatically the supply of petrol to the requirements of the engine, to adjust the heating of the incoming air and of the interior of carburettor to suit varying conditions of the atmosphere and different qualities of petrol, and to easily vary the mixture of gas and air.

The carburettor is cylindrical, Plate 131. The upper part contains a T tube, the top arms extending across the casing, forming a ready means of connecting with the petrol supply-pipe at the side most convenient for coupling up, the other being closed by a blank plug; the stem of the T extending downward is closed by a valve held against its seat by the stirrup S attached to the diaphragm D at the top of the chamber. A centre pin on diaphragm passes through the boss on the perforated cover, and is held up by the spring E, so adjusted that the rarefication of air in the chamber caused by the suction of the engine shall depress the diaphragm D, thereby opening the valve and allowing a few drops of petrol to be drawn into the chamber. This requires very nice adjustments, one for the tension of the spring, and another for the opening of the valve.

The screwed gland G serrated round its edge and retained by the spring F can be adjusted with the greatest nicety to regulate the beat or lift of the diaphragm and consequent opening of the valve; in fact, by screwing it sufficiently upwards the valve can be firmly closed. In practice, when the proper beat of the valve has been ascertained, the gland is intended to remain fixed. Adjustment of this gland G does not affect the ease of movement of the diaphragm and valve that is regulated by the spring E, the tension of which can be adjusted by the self-locking fly-nut N. As the valve has to open and close rapidly, it is desirable that it and its operating parts should be as light as possible. The diaphragm is therefore composed of thin oiled leather, supported and guarded by a " spun " metal disc.

From the valve the petrol falls upon a nest of wire-gauze washers or metal trays in the mixing chamber, from them it runs down the gills shown in the drawing into the well, where, if too much accumulates it can overflow through the bent pipe.

The mixing chamber is surrounded by the annular heating chamber C. Hot gases from the exhaust enter at one side and go cut at the other, the mid ribs R preventing a short egress. The adjustable slotted screwed cap P controls the amount of hot exhaust gas permitted to pass through the annular chamber, and so regulates the heat of the carburettor. To ensure the diffusion of heat within the mixing chamber the centre-gilled tubes U, Fig. 11, are inserted one above and one below the nest of wire-gauze washers.

To warm the incoming air the shell of the well extends upwards and surrounds the annular heating chamber, and is perforated round the upper portion by a number of small holes through which the air is drawn. An internal ring, also with perforations, acts as a hit-and-miss shutter regulating the inflow of air.

The flow of "mixture" to the engine and the necessary addition of fresh air is regulated by the lever L, operating a composite valve, part of which may be described as a hit-and-miss disc controlling the mixture, and part as a hit-and-miss cylinder controlling the fresh air. When one is fully open the other is closed, and any intermediate ratio can be obtained.

Wire gauze is inserted at WW to prevent back-firing into the carburettor.

Electric Ignition.—Perhaps of all the puzzling parts of a motor for road carriages none has given more trouble than that of ignition. To give the author's experimental experience in this detail alone would be wearisome. At one time he was a strong advocate for tube ignition, and much can still be said in its favour, and the design of engine shown permits tubes to be employed when desired; still, in the present state of the art he thinks that electric ignition is preferable, because it avoids the troublesome and dangerous lamp required for heating tubes, and permits variation in the time of firing.

Electric ignition can be effected in two ways, either by a low-tension current made and broken mechanically within the cylinder, or by employing a secondary high-tension current that shall spark across from fixed points within the combustion chamber, when the primary circuit is made and broken outside. Each of these rival methods has its advocates, time and experience will determine which is best; the author having experimented largely with both, at present prefers the second, though admitting that it is still attended with difficulties, the first being to obtain a good sparking coil, that will spark across a $\frac{3}{8}$-inch gap, and yet will not break down the insulation of the secondary windings, if the circuit is open when the primary circuit is closed.

Then comes the ignition plug itself, and the difficulty is such that makers hesitate to guarantee it. One plug may last many months and its fellow break down in a few hours; a reliable ignition plug is a thing to be desired, and as the author is not thoroughly satisfied with any that he has obtained or made, the one he now uses will simply be described as a plug. He would however emphasise the necessity of carefully and closely adjusting the sparking points and the maintenance of this adjustment; an apparently good fat spark when the plug is outside may, because of the high resistance of the compressed mixture, become valueless when in position.

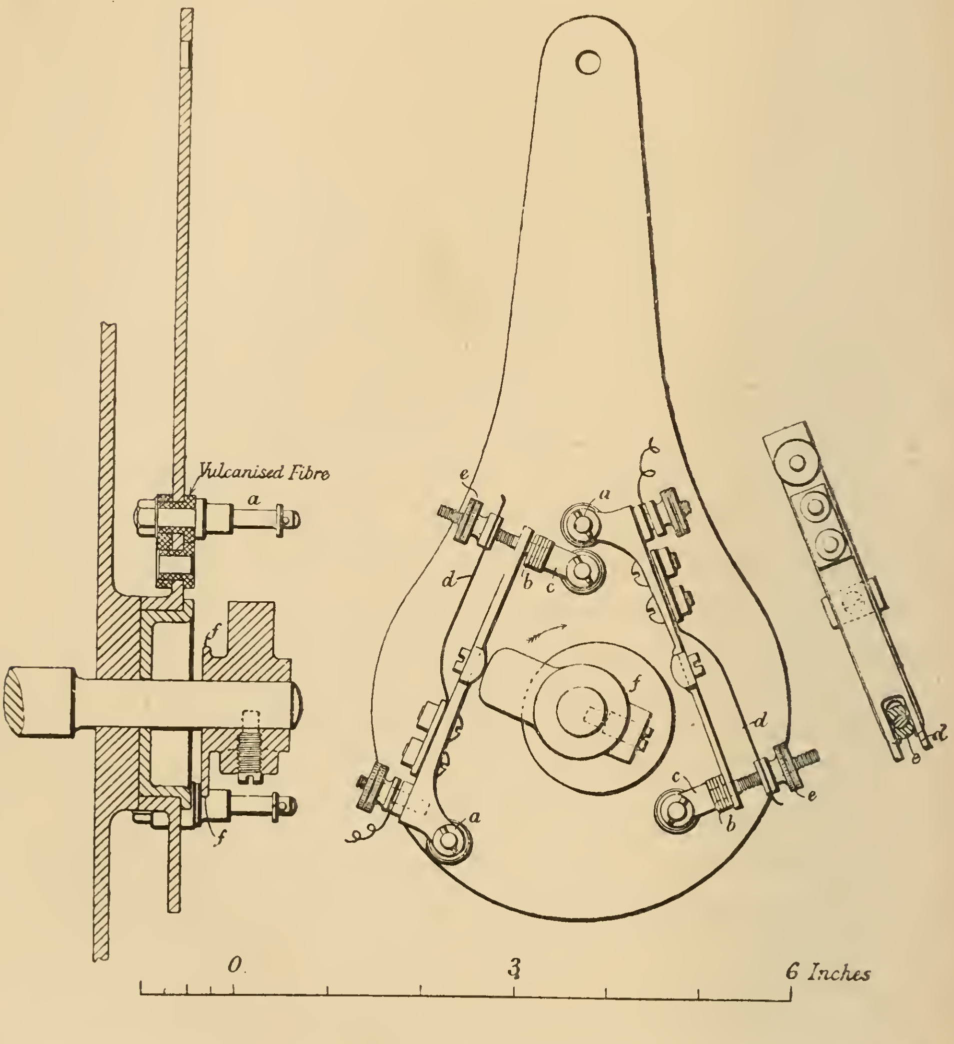
Having experienced considerable difficulty with the commutators supplied, owing chiefly to defective contact at the proper time, oil flooding, and occasional short circuiting, the one illustrated in Fig. 15 (page 710), was devised, the chief feature of which is that the pressure on the contact-making portions can be adjusted to any required degree without altering the position or range of movement. The contact-making pieces are pivoted at *a*, *a*, their inward movement controlled by the leather washers *b*, *b*, threaded on the rocking studs *c*, *c*, which extend beyond the back springs *d*, *d*, the compression of which can be adjusted by the self-locking nuts *e*, *e*.

To prevent oil from fouling the contact-making cam, a thin metal disc *f* is placed eccentrically on the back, and any oil that may leak through the bearing is by centrifugal action flung clear away before it reaches the cam.

The method of mounting and rocking the contacts forward or backward for altering the time of firing will be readily seen from the drawings. Travelling has been easier since this commutator was applied to the engine.

Cooling.—It is undesirable to rely upon natural circulation when very little "head" can be obtained and the water has to pass through a ramification of radiating pipes; also any plunger or rocking pump, though effective when the engine is running, practically blocks the circulation when the engine is standing. It was therefore decided to use a centrifugal pump, but as ordinarily constructed it gives

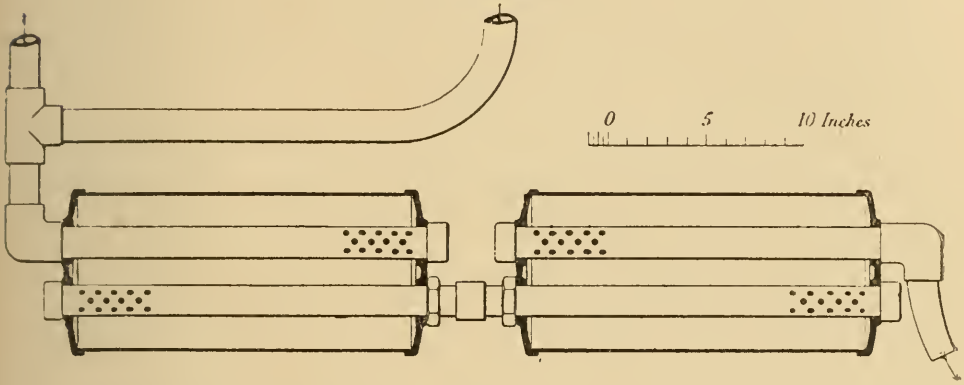
FIG. 15.—*Adjustable Contact Maker.*



trouble because, having to run at a very high velocity, it must be geared up, involving complication. A pump was therefore devised that could be coupled direct to the engine shaft, and after numerous experiments with accepted formulæ for the shape of the vanes, all of which had to be abandoned, one was made on quite unorthodox lines, which gives excellent results. The water passes through two sets of gilled radiating tubes that only differ in minor detail from devices ordinarily employed.

The noise of the exhaust is subdued by passing it in series through two drums of large capacity, the arrangement employed being shown diagramatically in Fig. 16, which hardly needs description.

Fig. 16.—*Muffler.*



Transmission Gear.—The chief and the only argument against the use of impulse engines for motor-cars is that they have to be kept running though the carriage is standing, and that it is desirable though not absolutely necessary that they should run at a constant high speed. This necessitates the employment of a clutch or its equivalent for engaging and disengaging the power and change gearing for varying the speed, because the moderation that can be obtained by governing the engine is not sufficient for hill-climbing, etc.

The requirements vary so much that some automobilists have advocated six changes of speed. Four is frequent practice, the speeds being say 10, 15, 20 and 25 miles an hour. This means a sudden jump from one speed to another, requiring skill on the part of the driver so to manipulate the friction clutch as to permit the necessary slip when the change is being made. An interesting Paper was read by Mr. Austin during the Automobile Show at the Agricultural Hall this year, on "The Transmission Gear of a Motor Carriage." The Paper concluded with eight deductions, the final one being—

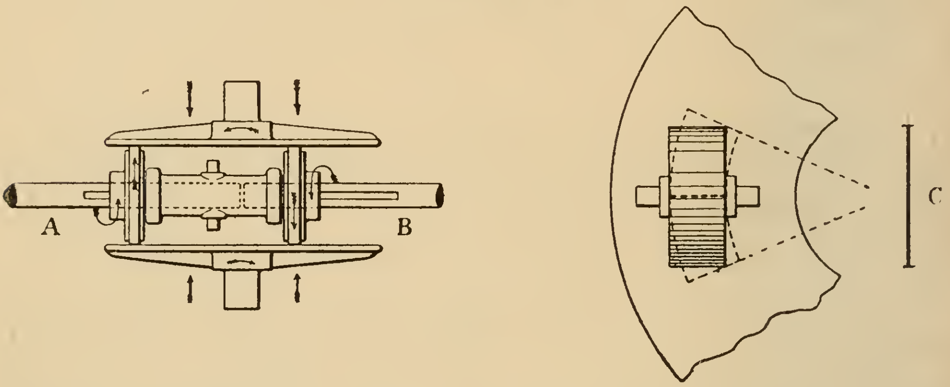
"The ideal gear would be one giving a gradual increase or decrease made to suit the gradient, and enabling the car to be started from stand-still quite gradually."

The author experimented many years ago in various directions for the attainment of this ideal end, with centrifugal and other pumps with varying blade or throw of pump acting upon a turbine also with adjustable vanes. The idea has since been better worked out by others.

Another scheme was the employment of disc gear, and the arrangement or its equivalent is so frequently reappearing that it is here shown diagramatically in the hope of preventing others wasting their time and money in a like manner.

In Fig. 17 A represents the driving shaft from the engine. B the driven shaft to the car wheels; each carries a roller clamped between two discs pressed together by adjustable springs. The roller on A drives the discs, the discs transmit the power to the roller on B. The rollers are shifted by the same sleeve and kept the same distance apart; when towards A, B runs slowly; when towards B, B runs quickly.

Fig. 17.—*Diagram of Disc Driving.*



For transmitting movement this would be all right, but for transmitting power there is the same so far unsurmounted difficulty of the grinding action of the rollers on the discs due to the different angular velocities of the parts in contact, which, unless the material employed is of a flexible and yielding nature, is simply a thin line. The difference in travel of the two edges of the roller due to one revolution on the disc is represented by the line C.

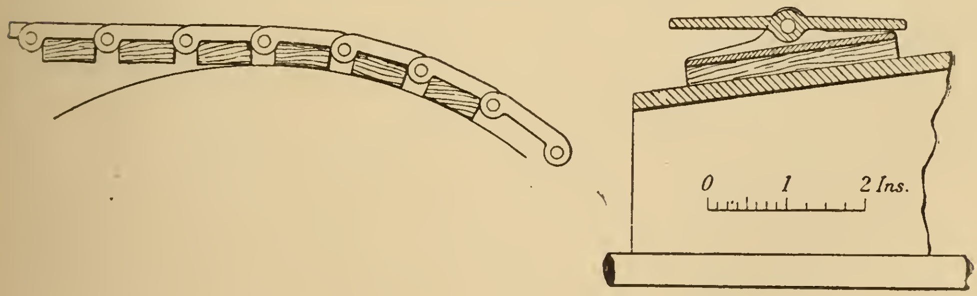
Next to discs, cones have been frequently suggested, and sometimes employed by those who have not realised the conditions involved, and have also been dismissed as impossible by those who, realising the difficulty, have not studied them sufficiently to arrive at a solution.

Let the case be stated simply; assume a cone 6 inches diameter at one end, 12 inches at the other, running at a constant speed of 600 revolutions per minute, driving a similar cone beneath it; assume a wire or ideal line coupling the two, at the 6-inch end of the driver cone, it then being on the 12-inch end of the driven cone will turn it at 300 revolutions per minute; shift the wire to the 12-inch end of the driver, the driven cone will then run at 1,200 revolutions per minute. But a wire will not transmit power, a belt of some width must be employed; assume (for the enforcement of the facts) that a belt is employed of the full width of the cones, the driver still running at 600, one edge of its belt is trying to turn the driven at 300 whilst the other edge is trying to turn it at 1,200 revolutions. Now the same thing happens, only in a less degree, with a belt of any width. The tendency to climb, etc., are only resultants of this fact. The problem to be solved is how to retain an ideal line for the varying ratio of speed and to employ a wide belt for the transmission of power.

For this purpose something must be arranged that will easily bend round the pulley and something that will accommodate itself to the slope of the cones; samples are exhibited of four different constructions to this end. It is only proposed to describe two.

Everyone is acquainted with linked leather belting; now assume a belt constructed of a series of hinged plates as shown in Fig. 18, and that the inner sides of these hinged plates were shod with leather; it

FIG. 18.—*Hinged Link-Belt on Cone Pulley.*



would then wrap round an ordinary pulley and drive in the same way as an ordinary link belt; now if the leather pads were held on separate shoes and so hinged to the chain belt that they can rock transversely thereto, they will be able to accommodate themselves to the slope of the cone, the chain-belt still running at right angles to the shaft as in ordinary belt pulleys.

The centres of the rocking pins form the ideal line for speed ratio and the width of the pads forms the wide belt surface for power transmission.

This belt is theoretically correct; it is however somewhat expensive to make, and it was found in practice to produce an unpleasant noise when applying the power, not whilst running; a more simple solution was therefore sought and arrived at as follows.

Fig. 19 represents the projection of the outer surface of a cone, the arc *a* being equal to the circumference of the smaller end, and

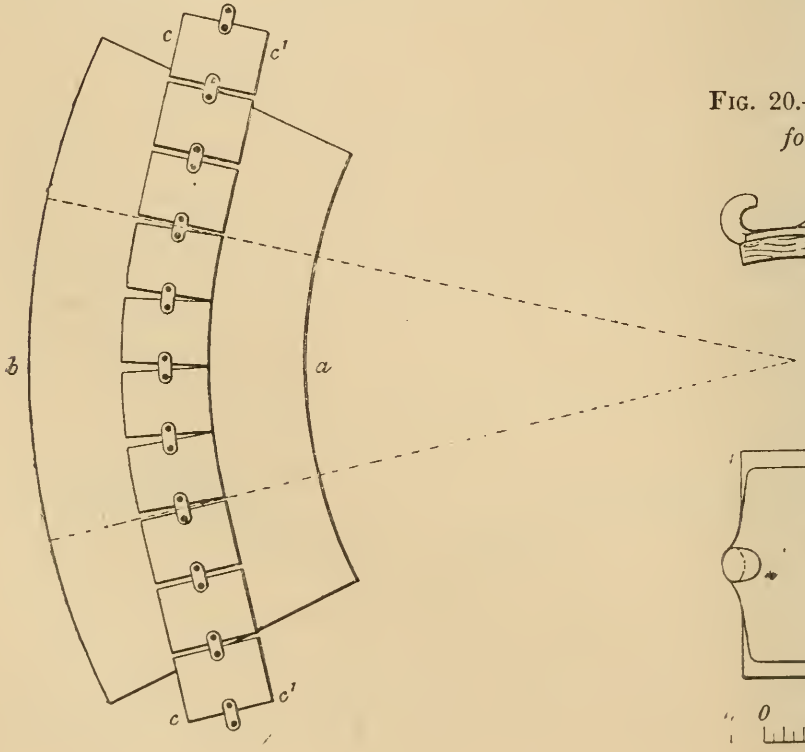


Fig. 19.—*Development of Belt on Cone Pulley.*

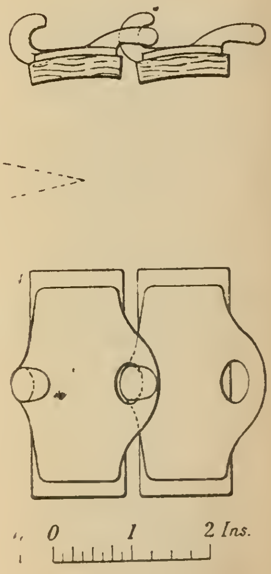


Fig. 20.—*Links as made for the Car.*

the arc b equal to the circumference of the larger end. The dotted lines show the length of half circumference; now if a belt were in mid-position on the cone, it ought when plotted to be as shown by the lines c, c and c^1, c^1; with an ordinary belt this formation would be impossible, some articulation is necessary; if a belt were cut up into short sections and pinned together as shown in the diagram, then the leather would give flexibility for wrapping round the pulleys, and the pin joints would permit accommodation to the cones; but leather that is flexible one way is flexible also another way, and the edges of the belt would turn up and have little grip on the pulley unless some cross stiffening arrangement were introduced. Difficulty would also arise when trying to shift the belt. Many experiments have been made in this direction. A simple solution that works well in practice is illustrated in Fig. 20, a series of metallic links are hooked together having cast upon their undersides a number of spikes as in the well-known belt fasteners; on to these spikes leather pads are driven, the hook and link permits the double accommodation, namely, to the circumferential bend and the conical curve.

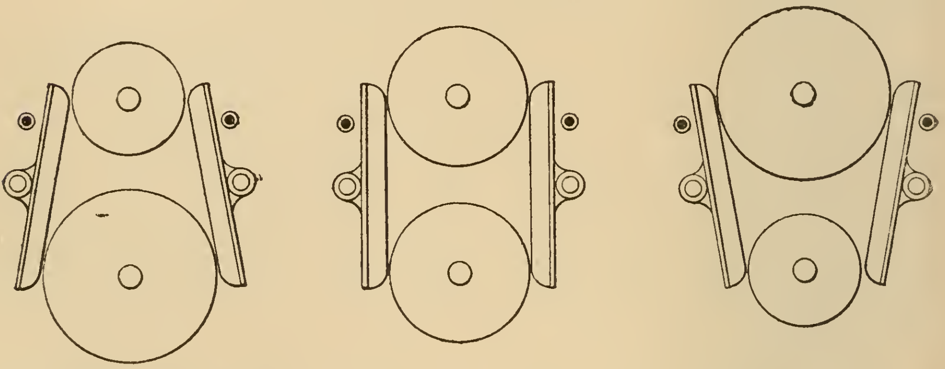
Having succeeded in solving the problem of power transmission from cone to cone, the next thing was so to apply it as to get the full benefit thereof. As already stated the impulse engine has to be kept running, and it is usual to employ a friction clutch for engaging with the gearing. Sometimes belts are used tightened by jockey pulleys or shifted from loose to fast pulleys. The Act of Parliament also requires that all automobile cars above 15 cwt. should be fitted with reversing gear.

Plate 132 shows how these requirements have been fulfilled. The top or driving cone is by a suitable coupling directly connected to the crank-shaft of the engine; its shaft also carries a grooved friction wheel, the bottom or driven cone is held in a fender, one side of which is pivotally attached to the framework of the car, whilst the other is free to move up and down controlled by the lever A and the screw B, the spindle of which passes upwards and is fitted with a crank handle or wheel within easy reach of the driver.

When the lower pulley is in mid-position the articulated belt is hanging slack and no power is transmitted; lowering the pulley tightens the belt, and power is communicated. When the lower cone shaft is lifted above the mid-position, then the grooved friction wheel upon it engages with the friction-wheel on the upper shaft, and power is communicated in the reverse direction. It will thus be seen that by simply turning a handle to right or to left the car can be started or stopped, made to go backwards or forwards. The lever A is so hung that when the brake pedal is pressed its first operation is to shift the fulcrum of the lever, releasing the tension on the belt and then to apply the brake. This is of great convenience and safety in practice.

To shift a belt upon cone pulleys, especially when they are so near together as is necessary in the present case, is no easy matter. The belt has to be guarded both sides of the cones, and these guards or guides have not only to slide longitudinally with the axles of the cones, but as they slide they must also tilt to correspond with the varying slope of the belt, as illustrated in diagrams Fig. 24.

Fig. 24.—*Belt Guides.*



An examination of Plate 132 will show how this has been accomplished. The guides are not only travelled forward and backward by the two screws, but they can also rock upon them, and the amount of rock is controlled by the upper rods placed at the required angle. The screws are operated by a hand-wheel on a shaft concentric with the power-applying wheel, connection being made by shafts and bevel wheels as shown.

From the lower cone power is by a shaft fitted with specially designed flexible couplings communicated to box gearing on the driving axle. To describe the gearing in detail would make this Paper too long, and though its construction might prove interesting, it is proposed to leave it for a subsequent Paper, together with the driving-wheels, tyres, steering device, brakes, under-frame, and other details.

The Paper is illustrated by Plates 129 to 133 and 8 Figs. in the letterpress.

Discussion.

The PRESIDENT said that, at the present time when motor cars were coming so prominently before the public, a Paper dealing with practical details and showing the results of experience was particularly valuable. The Members were extremely indebted to the author for having placed the results of his experience before them. He was sorry the time was so far advanced that it would be impossible to discuss the Paper, but the Members would be glad to hear from its final paragraph that the author proposed on a future occasion to write a supplementary Paper dealing with other details connected with motor-car construction. He hoped that Paper would be taken at a time when a considerable period could be devoted to the discussion of the whole details. The author had had such a large experience in motor-car construction, and had gone so very thoroughly in all matters of detail that such a discussion would be of the greatest value. He asked the Members to accord a hearty vote of thanks to the author for his most valuable Paper.

THE BARROW HEMATITE STEEL WORKS.

By Mr. ARTHUR J. WHILE, of Barrow-in-Furness.

The Works of the above Company being of considerable extent, the present Paper, which is intended more particularly as a guide to Members when visiting the Works, Fig. 1, Plate 134, must necessarily be of a somewhat cursory character.

The Company was established in 1861 with the object of developing on a large scale the vast and wealthy deposits of hematite iron ore of the district, and of manufacturing pig-iron and all descriptions of Bessemer and Siemens-Martin qualities of steel. The special suitability of hematite iron ore for steel manufacture—either by the Bessemer or the Siemens-Martin process—has been most strikingly shown, and the rapid growth of the Furness district and of its industries is a proof, if one were needed, of the value of this metal, especially now that steel is so largely used for all purposes where previously the best qualities of iron only were employed. The iron mines owned and worked by the Company are situated within 5 miles of the blast-furnaces.

Blast Furnaces.—The blast-furnaces, Fig. 2, are twelve in number, ten of which are 61 feet high and 18 feet 6 inches diameter at the boshes, and two are 70 feet high and 18 feet 6 inches diameter at the boshes. The number of tuyeres used varies at each furnace from seven to eight, each having 5-inch nozzles.

There are twenty-nine hot-blast stoves of various designs, four being Massicks and Crooks', two Whitwell's, nine Ford and Muncur's, and the remainder Cowper's, Plate 135. The newest stoves are of Cowper's design and are 70 feet high and 28 feet diameter, and heat the blast to a temperature of 1,500° Fahr. The blast is obtained from condensing beam-engines giving an average pressure of blast of 5 lbs. per square inch. Each furnace produces 750 tons per week of Bessemer iron. The whole of the iron made during the week is taken direct to a mixer, Plate 136, for use at the steel works, but the iron made at the end of the week is cast into pig-iron.

The materials, after being filled into iron barrows, are conveyed to the tops of the furnaces by an inclined tramway, and charged by hand on to the bell, which is afterwards lowered by the usual counterbalanced beam controlled by a rack and pinion arrangement. The ores smelted consist of both local and best foreign hematite, usually containing 50 per cent. of metallic iron. The coke used is principally obtained from Durham and Lancashire, and from the company's own collieries at Barnsley. The limestone is procured from the company's quarries situated 3 miles from the furnaces.

The blast-furnace slag is run into self-tipping bogies, Plate 137, and taken by narrow-gauge locomotives to the tip situated about half a mile from the furnaces.

The gases from the furnaces are utilised for heating the stoves and boilers.

Breaker.—This mechanical device for breaking pig-iron has just been introduced, Plate 138. It is placed upon a massive concrete foundation 13 feet 6 inches high, and is actuated by electric motors. The pig-iron is cast upon the pig beds in the customary manner, and when cool is picked up by means of a steam travelling-crane and placed upon wagons. These wagons are all taken to the machine where an electric travelling-crane lifts the comb of iron on to the breaker-girders, between which the feed table reciprocates. The machine is then put in motion, the table rises and the comb is carried forward under breaking rams, worked from an eccentric shaft, which bring sufficient force upon the pigs to break them, the broken pieces falling into a receiving wagon placed under a shoot on the other side of the machine.

Mixer.—The mixer, Plate 136, was the first receptacle for this purpose erected in this country having mechanical movement. It has a capacity of 120 tons of molten iron, nearly 6,000 tons passing through it weekly. The iron is conveyed by a locomotive from the mixer to the Bessemer shop in ladles of 18 tons capacity.

Bessemer Shop.—This is one of the most modern of European Bessemer shops, and contains four converters, each of 20 tons capacity, arranged in one row, and facing what is generally known as the pit. The converters are elevated sufficiently to allow the ladle, standing on a crane below, to receive the contents of steel, and also to allow a bogie on a road beneath the converter to receive the slag. Each converter is actuated by means of a powerful pair of vertical hydraulic rams having a rack-and-pinion acting in opposite directions. In front of the converters is a platform, supported by iron columns, to which access is obtained by an inclined roadway, along which the molten iron is brought from the mixer in ladles, Plate 139. The locomotive places the ladle of iron in front of the mouth of the converter, a hook engages itself on to a pin fastened on the ladle and lifts it up gradually until the whole of its contents are poured into the converter. When the ladle is emptied, it is again lowered on to the carriage and returned to the mixer to be re-filled.

Spiegeleisen is charged into the converter in a similar manner, the cupola being at the one end of the platform, and on the same level as the converter.

The converters are attended below by two transfer cranes, Plate 140, on which are placed the ladles for receiving the steel. These cranes transfer the ladles to a centre or casting crane from which the "heat" is cast into moulds. In addition to the ladle cranes, there are two smaller ones which serve for changing the ladles or any other pit work. All these cranes, although of different sizes, are of the same principle, namely, the top supported pillar having a wheel actuated by a ram and rack for the turning movement. This is a very simple arrangement, and is found to work admirably. The cranes are worked from an ordinary distributing box, from which the converter and lifts are also worked.

All the moulds are placed on bogies, each bogie carrying two moulds. They move forward under the nozzle of the ladle as required, the centre crane remaining stationary. The bogies are moved along by means of a finger fixed on a ram, which is situated on the floor level. Each mould is made to hold two tons of steel, and in order that the arrangement of casting should work well, about a hundred bogies are always in use, the consequence being that there is a constant stream of bogies and moulds in circulation, and by keeping them running in proper order, the moulds become cool by the time they are required without recourse to water cooling.

When the ingots have remained in the moulds ten minutes the bogies are drawn forward to the ingot stripper. This is a very useful machine, which, with a minimum of labour, strips the moulds from the ingots and places them on to an empty bogie that they may return to the yard to cool before being used again. The ingots still on the bogie, but stripped of their moulds, are taken to two gas-heated pits by a small locomotive. These gas-fired pits take the form of a long passage or channel 5 feet 6 inches wide and 6 feet 6 inches deep, at either end of which is a set of regenerators. There are five lids to each pit, and they hold twenty ingots, that is four ingots under each lid or door. The doors or lids are of cast-iron lined with bricks, and are supported by girders on which the four wheels of each lid run during the opening and closing. These doors are moved by a rack-and-pinion, actuated by a small hydraulic ram, and there is a clutch for each door. Each pit is served by a small crane similar to the serving cranes in the Bessemer shop, but with the addition of a racking-in motion.

When the ingots are of the proper heat, they are taken out of these pits by the same hydraulic cranes, and are placed upon a train of live rollers, which convey them to the cogging mill.

Cogging Mill.—This mill, Fig. 9, Plate 141, is a 36-inch train, driven by a pair of high-pressure horizontal reversing-engines, having cylinders 42 inches by 48 inches and geared 2 to 1. The rolls have five grooves, and the screws are fitted with a rack-and-pinion movement actuated by a ram, which lowers the rolls 2 inches so that the bloom receives a draught of 2 inches in passing through and returning. When the bloom has passed through the last groove of the cogging mill it runs on roller gearing to a shears where the rough ends are cut off. This prevents collars and other troubles arising during subsequent rolling.

Roughing Mill.—After shearing it passes in a straight line to the roughing mill. This mill consists of a 30-inch train, and is driven by a pair of high-pressure horizontal reversing-engines with cylinders 50 inches by 54 inches and working direct. In usual work a bloom makes five passes in this mill and then proceeds to the finishing mill.

Finishing Mill.—This mill, Fig. 10, Plate 141, is a 28-inch train, and the engines are similar to those at the roughing mill, except that the cylinders are 48 inches by 54 inches. There are five grooves here, after passing through which the bar proceeds on live rollers to the saw where it is cut into the requisite lengths. After sawing, each rail is placed on the hot bank by means of skids, of which there are four pairs, one pair for each bank. When the rails are cold they pass on roller gearing to the finishing bank where they are straightened, drilled, and finished in the customary way. The mill is capable of easily producing 5,000 tons per week.

Siemens Melting-Shop.—There are four Siemens furnaces of 50 tons capacity, Plates 142 and 143, one of 40 tons and three of 25 tons capacity. They are of the ordinary design producing about 1,500 tons of steel weekly. The gas for the Siemens furnaces is generated from a range of thirty-six ordinary Siemens gas-producers. There are three coal-fired horizontal heating furnaces for the slabbing mill arranged in semi-circular order, the curve being struck from a centre on which revolves a hydraulic charger and drawer. This charger receives the ingots from the pit-side crane, and with very little manual labour attends to the charging and drawing of the furnaces.

Slabbing Mill.—The heated ingots are then conveyed by a small locomotive to the slabbing mill, where they are rolled to any desired size, and cut (by means of a mechanical shears) into the necessary lengths to suit the order specified, and conveyed to the plate mills. The mill is driven by a pair of high-pressure horizontal reversing-engines having cylinders 36 inches by 42 inches, and is geared 3 to 1. The train is 36 inches with a lift of top roll of 16 inches balanced by hydraulic rams. The screws are driven by a pair of small engines.

Plate Mills.—There are two plate mills; the first is driven by a pair of high-pressure horizontal non-condensing engines having cylinders 50 inches by 54 inches. The train is 28 inches, and consists of two pairs of rolls each 7 feet 6 inches long, and rolls plates from $\frac{1}{4}$ inch to 2 inches thick. The slabs are heated by four ordinary coal-heated furnaces served by a charging and drawing machine similar to that at the slabbing mill. There are live rollers on both sides of the rolls and a skid arrangement to convey the plates from the soft to the hard rolls. The plates when cool are conveyed to the shears by a steam travelling-crane having a span of 70 feet.

The second plate-mill is driven continuously by a vertical beam-engine of an old type. The soft rolls are three high, and the finishing are two high, the rolls in both cases being 6 feet long, and the train 26 inches. This mill receives slabs about 4 inches thick, and rolls all those received which are too thin for the large mill, namely, from $\frac{1}{8}$ inch to $\frac{1}{4}$ inch inclusive.

Merchant Mill.—This mill has an 18-inch train of rolls, and is driven by a pair of horizontal engines with cylinders 33 inches by 48 inches. It is used for the rolling of fish-plates, light rails, angles, bars, &c., from 4-inch billets.

Tram-Rail Mill.—This is driven by a pair of high-pressure horizontal reversing-engines with cylinders 42 inches by 48 inches having Corliss valves, and is geared 3 to 1. The mill consists of two pairs of rolls and is a 28-inch train. The mill is also used for the rolling of girders, angles, channels, sole-plates, &c.

Foundries.—The foundries, of which there are five, namely, three for the production of steel castings, one for making ingot moulds, and one where all the brass castings are made, are well equipped with stoves and powerful cranes, the latter serving to cast, and afterwards lift, the heaviest stern frames, rudder frames, rolls, and other large castings.

The small steel foundry, which is used for the production of small steel castings, possesses a 7-ton Siemens furnace having a Duff gas-producer alongside.

Roll-Turning Shop.—This shop has nine lathes, and is designed on the best known principle. It is provided with an overhead rope travelling-crane which runs the whole length of the shop.

Engineering Shops.—These are extensive and comprise the machine shops and subsidiary shops, namely, the boiler, smiths', wagon-building, saw-making, pattern-making shops, &c., and saw-mills, all containing fine tools of recent date. It is in these shops that the machining and finishing of the marine castings takes place, as well as the construction of all the firm's own new work, and repairs.

Electrical Installation.—This consists of two dynamos each giving 750 ampères at 220 volts, driven by two vertical non-condensing engines and one dynamo of 300 ampères at 120 volts, driven by a horizontal engine which also drives the shop machinery. These three dynamos supply the necessary electricity for 1,500 incandescent lamps, 130 arc lamps, and 12 motors.

General.—There are 60 steam boilers, Plate 144, in use at the iron works and 105 at the steel works, and 15 broad-gauge and 15 narrow-gauge locomotives employed.

The wire works is situated at a short distance from the steel works, and contains a rod mill and two hoop mills.

Other departments of the works are the general offices, laboratory, drawing office, testing house, stores, &c.

The total number of hands employed is about 3,500, exclusive of those at the coal and iron mines, which are extensive, and about 250 at the wire works. The area of the land occupied by the company's works, including railway sidings and reservoirs, is 245 acres.

The Paper is illustrated by Plates 134 to 144.

HISTORY OF THE FURNESS RAILWAY LOCOMOTIVES.

By Mr. W. F. PETTIGREW, *Member*, of Barrow,
Locomotive, Carriage, and Wagon Superintendent.

As the Members of this Institution are visiting the district served by the Furness Railway, it will no doubt be interesting to many of them to learn something of the locomotive engines that have at different times been in use on that line.

The first portion of this Railway was opened in 1846, from Kirkby to Dalton and Piel Pier for mineral traffic; passenger traffic commenced in December of the same year. After this, various amalgamations and extensions took place to Carnforth, Coniston, &c. In 1866 the Whitehaven and Furness Junction Railway, extending from Whitehaven to Broughton, along with nine locomotives, was taken over. Following this the Furness Railway became joint owners with the London and North Western Railway of the Whitehaven, Cleator, and Egremont Railway, at the same time taking over sixteen locomotives. The traffic on this railway has been chiefly goods and mineral, three-fourths of the locomotives being so employed, although the passenger traffic has made great progress during the last six years.

The principal works are at Barrow-in-Furness, Plate 156, whilst running sheds are provided at Carnforth, Moor Row, and Whitehaven. The total miles worked by the engines are 170½.

The locomotive engines in use in the early days of the Furness Railway Company were of the "Bury" class. Many of the Members have no doubt seen the "Old Copper Nob," No. 3, Plate 145, which is so called owing to its dome-shaped fire-box with copper casing. The first engines of this type for this railway were built in 1844, and numbered 1 and 2. Unfortunately there are no drawings of these engines, although they were practically similar to Nos. 3 and 4 delivered two years later, with the exception of the cylinders, which were 13 inches diameter, and the working pressure 80 lbs. per square inch. The life of the first two was short compared with Nos. 3 and 4, for in 1866 No. 1, whilst stationed at Carnforth, had the fire-box badly burned, owing to the fire having been lighted with an empty boiler, so that it was decided to break her up. No. 2 was afterwards sold to a Northumberland colliery in 1871.

Nos. 3 and 4, Plate 145, built by the same makers—Messrs. Bury, Curtis and Kennedy, Liverpool—were delivered in 1846; these have had an exceptionally long career, No. 3 having been worked up to within a year ago. A few particulars concerning the dimensions of these engines will no doubt be of interest. They had inside cylinders 14 inches diameter by 24 inches stroke, the slide-valves being placed between the cylinders in the usual manner. The width of steam ports is $1\frac{1}{4}$ inch, exhaust 3 inches by $10\frac{1}{2}$ inches long, and lap of valve $\frac{3}{4}$ inch. Each cylinder is a separate casting, both of which have a separate exhaust-pipe which converges at the mouth of the chimney into one. The wheels are four-coupled 4 feet 9 inches diameter on tread; the centres are of wrought-iron with cast-iron bosses, and had iron tyres secured to the rims by 1-inch bolts. The main bearings are $5\frac{1}{4}$ inches diameter by 7 inches in length, and the crank pins $2\frac{1}{4}$ inches diameter by $2\frac{3}{4}$ inches in length.

The engine frames, which are of the bar type, have upper and lower members united by the pedestals; the frames are of rectangular section 4 inches by 2 inches, and the lower bar $2\frac{3}{8}$ inches diameter. The axle-boxes are of gun-metal. The motion is of the curved link type, the eccentric-rods being coupled direct with crossed rods, and the links are suspended from the bottom. The sheaves are of cast-iron with gun-metal eccentric straps. The connecting-rods are round and have fork ends, all the brasses being secured by means of the double gib and cotter. The boiler plates throughout, with the exception of fire-box, consist of Low Moor iron, the barrel being made up of three rings; each ring is of two plates $\frac{7}{16}$-inch thick, the back ring being flanged back to join the fire-box casing, the crown of which is in the form of a dome, made up of no less than twelve plates, eight of which go to make the crown. The seams throughout are single-riveted lap with $\frac{3}{4}$-inch rivets.

The fire-box is of copper, semicircular in plan with a curved crown, and made up of four plates $\frac{9}{16}$-inch thick, the tube plate being $\frac{3}{4}$-inch thick. The crown plate originally consisted of two plates, a lap seam running longitudinally, which at times gave trouble; it is supported by four solid roof-bars of wrought-iron which are secured by 1-inch rivets, and connected to the outer shell by eight sling-stays $1\frac{1}{2}$ inches diameter. The sides are stayed throughout by copper stays screwed into both plates and riveted over; they are $\frac{7}{8}$-inch diameter and 4 inches centre to centre. The foundation ring is 4 inches by $1\frac{1}{2}$ inches, excepting at the front end which is 4 inches by 2 inches, the plates being set back to allow for a $2\frac{1}{2}$-inch water space. The front tube plate is $\frac{5}{8}$-inch thick, and is attached to the barrel by two gusset stays. The tubes were brass, $2\frac{1}{4}$ inches external diameter, and pitched $2\frac{5}{8}$ inches centres. Inside the dome is placed the regulator valve, which is of the equilibrium type, with a main steam-pipe 4 inches diameter to cylinders. The safety-valves are fixed on the dome with valves $2\frac{1}{2}$ inches diameter, the springs of which are adjusted for a working pressure of 110 lbs. per square inch. The smoke-box is of iron plates $\frac{5}{16}$-inch thick, and the chimney is also of iron with a copper top. The total heating surface is 854 square feet, and grate area 9 square feet, and the total weight in working order of the engine is $19\frac{1}{2}$ tons.

The tender, which has a capacity of 1,000 gallons, has the underframe constructed entirely of oak, and was fitted originally with a buffing spring similar to those used on wagon stock. The wheel centres were of cast-iron with wrought-iron tyres, 3 feet $1\frac{1}{2}$ inches diameter on tread, with a wheel-base of 6 feet 8 inches. The total weight in working order of the tender is 12 tons 18 cwts. These engines were of late years used as shunting engines at the Barrow Docks. It will be of interest to know that it has been decided to preserve No. 3 engine, which will afford many people an opportunity of seeing a "Copper-nob" engine with such a record. No. 4 engine has recently been broken up.

Up to the discovery in 1851 of large ore deposits in the district, these four engines were found capable of dealing with the traffic. It was then decided to order two more engines from Messrs. Sharp Brothers of Manchester (now Messrs. Sharp, Stewart and Co., Glasgow), which were delivered in 1852. They were numbered 5 and 6, and are shown in Fig. 2, Plate 146. They had single-driving wheels, 5 feet 6 inches in diameter with tank under the foot-plate. Owing to the increase in the traffic four engines were ordered from Messrs. Fairbairn and Sons, Manchester, shown in Fig. 3, Plate 146, Nos. 7 and 8 being delivered in 1854, and Nos. 9 and 10 in 1855. These engines were of the "Bury" type with dome-shaped fire-box and bar frames, although the cylinders had the valve placed on the top, the motion being worked by means of rocking shafts. The principal dimensions are:—cylinders 15 inches by 24 inches, wheels 4 feet 6 inches diameter, total heating surface 940 square feet. The total weight of engine and tender is 36 tons in working order. After forty-five years' hard work, two of these engines are still at work shunting at the docks; the others have been replaced.

The next engines delivered were two tank engines with single driving wheels, built by Messrs. Sharp Brothers in 1857, and numbered 11 and 12, being of the standard design of that period and similar in all respects to the engines shown on Fig. 4, Plate 147, with the exception that the cylinders were only 14 inches diameter. Both these engines were replaced, No. 11 being sold to Messrs. Sharp, Stewart and Company in 1875, and No. 12 being renumbered 12A, and was sold in 1898 to the Clevedon and Portishead Light Railway.

Four more engines were ordered from Messrs. Fairbairn and Sons, which were numbered 13 to 16, the first two being delivered in 1858 and Nos. 15 and 16 in 1861. They were of the same dimensions as shown in Fig. 3, Plate 146.

In 1863 four four-wheel coupled goods engines, Fig. 5, Plate 147, were built by Messrs. Sharp, Stewart and Co., of their own design, and numbered 17 to 20. The dimensions were, cylinders 15½ inches by 24 inches, and coupled wheels 4 feet 9 inches diameter. The heating surface was 926 square feet, and the weight of engine in working order was 24 tons 18 cwts. These four engines were sold to the Barrow Hematite Steel Company in 1870, being converted into saddle-tank shunting engines for them by Messrs. Sharp, Stewart and Co., and are still working.

Two single-wheel tank engines were built by Messrs. Sharp, Stewart and Co. in 1864, with driving-wheels 5 feet 6 inches diameter and numbered 21 and 22, Fig. 4, Plate 147. They had outside frames, the cylinders being 15 inches in diameter by 18 inches stroke, and the heating surface 858 square feet. They were well designed engines, and with light trains were very economical. Latterly, however, they were chiefly used for branch lines. They were replaced in 1896, No. 22 being sold to the Whitburn Colliery Company and No. 21 to a firm at Wigan. Two four-wheel coupled saddle-tank shunting engines, Fig. 6, Plate 148, were purchased from Messrs. Sharp, Stewart and Co. in the same year. The cylinders are 14 inches diameter by 20 inches stroke, wheels 4 feet diameter, heating surface 669 square feet, and the weight in working order 24 tons 10 cwts. These engines are still working on the docks. In 1865 two four-coupled engines, Nos. 25 and 26 were supplied duplicate in all respects to those before mentioned and shown on Fig. 5, Plate 147. These were sold to the Barrow Hematite Steel Company, and converted into saddle-tank engines.

In the year 1866 the Furness Railway Company acquired the Whitehaven and Furness Junction Railway, also nine engines which belonged to that company. Very little data concerning these engines can be found. They were accordingly numbered 42 to 50 in the books of the Furness Railway; these have all been sold, with the exception of No. 42 shown in Fig. 7, Plate 148. This engine was built by Messrs. Hawthorn; it is a six-wheel coupled goods engine, having cylinders 16 inches diameter by 24 inches stroke, and wheels 4 feet 6 inches diameter. No. 43 was of similar pattern built to the designs of Mr. Meekly, the locomotive superintendent. It was afterwards sold to Messrs. Fletcher, Jennings and Co. in 1873. Nos. 44 and 45, which were also built by Messrs. Hawthorn, were tender engines having cylinders 14 inches diameter by 20 inches stroke.

No. 46 was a single driving-wheel tank engine built by the same makers in 1861, having cylinders 14 inches diameter by 20 inches stroke, driving wheels 5 feet 6 inches diameter, and leading and trailing wheels 3 feet 6 inches diameter. This engine was sold to the Isle of Wight Central Railway. Nos. 47 and 48 were single driving-wheel tank engines, Fig. 9, Plate 149; they had cylinders 12 inches diameter by 18 inches stroke, driving wheel 5 feet 3 inches, and were built by Messrs. E. B. Wilson and Co., of Leeds. Both these engines were afterwards sold. Nos. 49 and 50 were saddle-tank shunting engines, having cylinders 10 inches diameter by 16 inches stroke, four wheels coupled 4 feet diameter. No. 49 was built by Messrs. Fletcher, Jennings and Co. in 1862, and No. 50 by Messrs. Neilson and Co. in 1861; both of which were sold to a Whitehaven firm in 1883.

In 1866 the traffic had increased so much that fifteen engines were ordered from Messrs. Sharp, Stewart and Co. The first two, Nos. 27 and 28, were duplicate of Nos. 17 to 20, Fig. 5, Plate 147, as it was thought up to that time the wheel-base was quite sufficient for the many sharp curves on this railway. Nos. 29 to 33 and 38 to 41, however, were of the six-wheel coupled type. These were until recently the standard goods engine throughout the system. The coupled wheels are 4 feet 6½ inches diameter and cylinders 16 inches diameter by 24 inches stroke, total heating surface 959 square feet, and the tractive force 8,360 lbs. They had four-wheel tenders, the engine and tender weighing complete in working order 50½ tons. These engines, Fig. 8, Plate 149, are all still working. Several of this class of engine have since been fitted with the automatic vacuum and steam brake for passenger working; new cabs have also been fitted. Several also have had new steel boilers fitted of a much larger type, with flush top and Ramsbottom safety-valves, giving a much larger heating surface and grate area with economical results. Four engines purchased in 1866 had single-driving wheels and well tank, duplicate in all respects of Nos. 21 and 22, Fig. 4, Plate 147; all of these were replaced in 1896, and afterwards sold.

In 1867 it was found necessary to introduce a new class of tank engine to assist in banking the goods and mineral trains between Plumpton and Lindal, which is about 3½ miles, with a gradient at some points of 1 in 76, also between Askam and Lindal, a distance of 5½ miles and gradients of 1 in 63. They have cylinders 18 inches diameter by 24 inches stroke, six wheels coupled 4 feet 7½ inches diameter, and are well adapted for banking; the weight in working order is 44 tons 14 cwts., and they are numbered 51 and 52, and shown in Fig. 10, Plate 150.

The single-wheel tank engines were found unable to haul the increased length of trains consequent on the increase of passenger traffic. It was therefore decided to order a new class of passenger engine of more powerful design, shown in Fig. 11, Plate 150. They were four wheels coupled with leading wheels, cylinders 16 inches diameter by 20 inches stroke. All these engines were constructed by Messrs. Sharp, Stewart and Co. The first engines were delivered in 1870 and numbered 1 and 2, replacing the old Bury engines. Up to within recent years these have been the standard passenger engines of this company, and are still working. As in the goods class they have all been fitted with the automatic vacuum brake; some have also had new steel boilers of a modern type, giving a much better appearance, and with more economical results in working. The last two of these engines were numbered 57 and 58. At the same time 18 more of the standard goods engines were ordered, and were numbered 17 to 20, 43, 53 to 56, and 59 to 67. They were built in 1871. Two more six wheels coupled bank engines were delivered in 1872, being exact duplicates of the former ones. These were numbered 68 and 69. In the same year, nine of the four-wheeled coupled passenger engines were delivered, which were of the standard pattern already described and numbered 47 and 48, 70 to 75. Owing to the increase in passenger traffic on the branch lines of the company, it was decided in 1891 to convert Nos. 47, 48, and 70 to 74 into tank engines, this traffic up to then having been worked by the single-wheel tank engines, which were becoming too light to deal with the heavy trains. The frames of the four-wheel coupled engines were lengthened, and a pair of radial wheels added, the tank having a capacity of 1,000 gallons. These engines are as shown altered in Fig. 12, Plate 151, and are still working.

Twelve new goods engines, four passenger engines and two bank engines, all of which were supplied by Messrs. Sharp, Stewart and Co., of the same designs as those previously described, were built for the company in 1873. Six goods engines were numbered 25, 26, 76, 77, 78, 79, two bank engines Nos. 82 and 83, then six goods engines Nos. 80, 81, 84 to 87, and finally four passenger engines Nos. 5 and 6 and 11 and 12. The two latter have since been numbered 3 and 4, replacing the old "copper-nob" engines, the vacant numbers being used for the new goods engines. Two years later six more standard goods engines were delivered, and numbered 88 to 93, and also four saddle-tank shunting engines similar in design to No. 23 class, but the dome was placed on the boiler instead of over the fire-box as in previous engines. They were numbered 94 to 97, and are still working.

Owing to the purchase of the Whitehaven, Cleator, and Egremont Railway, sixteen engines were taken over by the Furness Railway Co., and were numbered 98 to 113, and, with the exception of two, were all of the saddle-tank type six-wheel coupled engines, twelve of them built by Messrs. Stephenson and Co., of Newcastle-on-Tyne in 1878. Fig. 13, Plate 151, gives an outline of Nos. 98 and 99, the former built by the latter firm in 1855. The cylinders are 17 inches diameter by 24 inches stroke, coupled wheels 4 feet 6 inches. The weight in working order is 44 tons. The other engines of Messrs. Stephenson's design and build were Nos. 101 to 107, 109 to 111. All these engines have had new steel boilers fitted. The original boilers were of iron, and the longitudinal seams being lap-jointed were a frequent source of trouble; one gave way in 1890 whilst working, but fortunately without injury to any person. The back and front plates are stayed by gusset stays, and the frames are double with outside cranks. No. 100 was of a similar type, built by Messrs. Fletcher, Jennings and Co. in 1858; No. 102 was built in 1862, and

Nos. 103 and 104 in 1863, Nos. 105 in 1867, 106 in 1869, Nos. 107 and 109 in 1870 and 1871 respectively, and Nos. 110 and 111 in 1873. No. 112 was very similar to the latter engines, but was built by Messrs. Barclay and Co. of Kilmarnock in 1875. This engine has since been numbered 108. Both the engines Nos. 108 and 113 had side tanks, the former being a four-wheel coupled passenger engine with the outside cylinders 15 inches diameter by 20 inches stroke; the coupled wheels were 5 feet 3 inches diameter. This engine is shown on Fig. 14, Plate 152; it is the only outside cylinder engine on the Furness Railway, and was built by Messrs. Slaughter and Co., but at what period is not known. No. 113 was a six-coupled side-tank engine built by Messrs. R. and W. Hawthorn in 1857, Fig. 15, Plate 152, and sold in 1897, the number being taken by one of the new eight-wheeled tank engines. This is a fair general outline of the engines taken over from the Whitehaven, Cleator, and Egremont Railway.

Six standard goods engines were ordered from Messrs. Sharp, Stewart and Co. in 1881, which were numbered 114 to 119, all of which were duplicate in every respect to those already supplied. It will no doubt be of interest to know that it was one of these engines—No. 115—which was totally lost whilst shunting on Lindal Bank on 22nd September 1892, owing to the subsidence which took place. The tender was recovered, but the engine sank out of sight, the ground being subsequently made good above it. Following these it was found necessary in 1882 to replace Nos. 44 and 45, and 49 and 50 of the old Whitehaven class. Nos. 44 and 45 were replaced by 16-inch standard passenger type, and Nos. 49 and 50 by 16-inch standard goods, all built by Messrs. Sharp, Stewart and Co. There were also two more standard goods engines ordered, Nos. 121 and 122; but these were sold on arrival to the Liverpool, Southport and Preston Junction Railway.

No more new engines were added to stock until 1890, at which time four new four-wheel coupled bogie passenger engines of Messrs. Sharp, Stewart and Co.'s design were delivered, and were numbered from 120 to 123. These engines were the first on this railway to have the leading bogie. The principal dimensions are cylinders 17 inches diameter by 24 inches stroke. The weight of engine and tender in working order is 60½ tons; an outline of the engine is shown in Fig. 16, Plate 153. Owing to the increased weight of trains it was found necessary to introduce a still larger type of bogie passenger engine; these were delivered in 1896. They are shown in Fig. 17, Plate 153, and are of the following dimensions:—cylinders 18 inches diameter by 24 inches stroke; coupled wheels 6 feet diameter, bogie wheels 3 feet 6 inches diameter, total heating surface 1208·5 square feet, grate area 17 square feet, and weight of engine and tender in working order being 69½ tons. In 1897 it was found to work the great increase in goods traffic economically in the Cleator district that larger engines were required, and it was decided to design a powerful tank-engine to replace those already shown in Fig. 13, Plate 151. Three of these were ordered from Messrs. Sharp, Stewart and Co., and were delivered in 1898, and numbered 112 to 114; they are eight-wheel side-tank engines, six of which are coupled, and are shown in Fig. 18, Plate 154. The cylinders are 18 inches diameter by 26 inches stroke, coupled wheels 4 feet 8 inches, and trailing radials 3 feet 8½ inches, rigid wheel base is 14 feet 5 inches, and the total wheel-base 20 feet 8 inches. The boiler is 4 feet 4 inches diameter, and barrel 10 feet 6 inches in length. The length of fire-box casing is 6 feet 9 inches, giving a grate area of 20·5 square feet, heating surface being tubes 1,029 square feet, and fire-box 105 square feet, making a total of 1,134 square feet. Working pressure is 150 lbs. per square inch. The tanks have a capacity of 1,400 gallons, and the coal bunker 30 cwts. The total weight in working order is 55 tons.

By this time the main line goods traffic was severely testing the engines with cylinders 16 inches diameter, owing to the heavy gradients and great weight of trains, particularly between Plumpton and Lindal, which is 3½ miles long with a gradient 1 in 76 on the down road, and from Salthouse Junction to Lindal on the up road, about 5½ miles long with gradients 1 in 63, and in places with 8 and 10 chains curves. The trains consist of minerals, iron ore, pig iron, coal, coke, etc., all of which are very heavy to haul. It was therefore decided to design a much more powerful engine, duplicating as far as possible the details of the six-wheel coupled radial tank engine. The boiler, cylinders, wheels, motion, etc., are all from the same drawing, the tender being a duplicate of those supplied with the 18-inch passenger engine, Fig. 17, Plate 153. The first six of these powerful engines were built by Messrs. Nasmyth, Wilson and Co., Patricroft, and six by Messrs. Sharp, Stewart and Co., and are shown in Fig. 19, Plate 154. The wheel centres are of cast steel with the balance weights cast solid. The boiler is steel throughout, with copper fire-box. The weight of engine in working order is 38 tons 3 cwts. The engines are fitted with automatic vacuum and steam brakes, making them suitable for working the heavy passenger excursion trains. The tenders carry 2,500 gallons of water, with a coal capacity of four tons. The weight of the tender in working order is 28 tons 5 cwts. Several of the engines are fitted with Macallan's variable blast pipe, the smaller diameter being 4¾ inches and the larger 5¼ inches diameter. Some of the engines are also fitted with the exhaust injector, which show an economy in the coal consumption compared with those not fitted. These engines, which have now been running nearly two years, are hauling the mineral traffic at a very much less cost per ton-mile than the older engines. It has also been found necessary to provide more powerful passenger engines, as the 16-inch four-coupled engines were practically no use for the greatly increased passenger traffic. The principal dimensions of the new engines are as follows:—cylinders 18 inches diameter by 26 inches stroke, four-wheels coupled 6 feet 6 inches diameter with the leading bogie 3 feet 6 inches diameter. The boiler barrel is 4 feet 4 inches diameter and 10 feet 8 inches long, and the fire-box 6 feet long. The tubes have a heating surface of 1,159 square feet, and fire-box 111·5 square feet, making a total of 1,270 square feet. The grate area is 18 square feet, and the weight of engine in working order is 43 tons, and the working pressure 160 lbs. per square inch. The tender is a duplicate of the other tenders, excepting the water capacity has been increased to 3,000 gallons, and the wheel base to 13 feet, instead of 12 feet. The tank is also being carried 2 feet above the platform at front end, and is provided with a fence for coal; this engine and tender are shown in Fig. 20, Plate 155. It might here be mentioned that only four of this class were actually built, namely, Nos. 126 to 129. The first two—Nos. 124 and 125—were made duplicate, with the exception of alterations to the motion and valve gear, of the previous express engines, the reason being on account of delivery. The whole of these engines have now been delivered, and are proving equal in all respects to what was expected from them.

The Paper is illustrated by Plates 145 to 156.

EXCURSIONS.*

On TUESDAY AFTERNOON, 30th July, after luncheon in the Naval Construction Works, by invitation of Messrs. Vickers, Sons and Maxim, the Members were conducted round the Marine-Engine and Ordnance Works, Floating Dock, and Shipyard, under the guidance of Messrs. Vickers, James Dunn, and James McKechnie, Directors, and other officers of the company. The following Works were open to the visit of the Members during the Meeting:—

Corporation Electricity Works, Buccleuch Street.
Corporation Water Works.
Corporation Sewerage Works.
Barrow Salt Works, Reservoir, Filters, and Brine Wells, Walney Island.
British Griffin Chilled Iron and Steel Works, Ainslie Street.
Furness Brick and Tile Works, Walney Road.
Kellner-Partington Paper Pulp Works.
G. and T. Lee and Co.'s Rope Works.
Walmsley and Smith, Corn Mill, Hindpool Road.

On WEDNESDAY AFTERNOON, 31st July, the Members were entertained at luncheon in the Old Town Hall by the Worshipful the Mayor, Councillor Henry Cook, J.P. They then visited the Barrow Hematite Steel Works, under the guidance of Mr. J. M. While and Mr. A. J. While, whose Paper (page 719) described these Works. Afterwards the Members proceeded to the Furness Railway Locomotive, Carriage, and Wagon Works (page 754), which were visited under the guidance of Mr. Alfred Aslett, Secretary and General Manager, and Mr. W. F. Pettigrew, Locomotive Superintendent.

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* The notices here given of the various Works, &c., visited in connection with the Meeting were kindly supplied for the information of the Members by the respective authorities or proprietors.

In the evening the Institution Dinner was held in the Old Town Hall. The President occupied the chair; and the following Guests accepted the invitations sent to them, though those marked with an asterisk (*) were unavoidably prevented from being present.

The Deputy Mayor, Mr. Councillor Chapman, J.P.; the Right Hon. the Earl of Rosse, K.P., D.C.L., LL.D., F.R.S., Honorary Member; Sir Charles W. Cayzer, M.P.*; Mr. Councillor Alfred Barrow*; Mr. Alderman Bradshaw; Mr. J. E. H. Clarke, J.P.*; Rev. E. F. Crosse; Mr. Thomas Danks*; Lieut. A. Trevor Dawson*; Mr. Councillor William Dawson*; Mr. Councillor Joseph Huartson; Mr. Alderman Walton Lee, J.P.; Mr. E. Windsor Richards,* Past-President; M. Alfred Sire, Northern of France Railway; Mr. Alderman Strongitharm; Mr. Albert Vickers*; Mr. James Vickers; Mr. T. E. Vickers, C.B.; and Mr. Edward Wadham, J.P., Director of the Furness Railway.

Reception Committee.—The Worshipful the Mayor of Barrow, Councillor Henry Cook, J.P.,* *Chairman and Convener*; Mr. Archibald Miller, *Honorary Secretary.* Mr. Frank S. Ainslie*; Mr. John Aird*; Mr. Alfred Aslett, Secretary and General Manager, Furness Railway; Mr. William Barratt; Mr. James H. Boolds*; Mr. A. Bradbury; Mr. A. Butchart; Mr. James Dunn, J.P., *Convener*; Mr. William Fleming*; Mr. W. H. Fox,* Borough Engineer; Mr. James Gunson, Borough Treasurer; Mr. J. M. Hay*; Mr. William Kellett*; Mr. Myles Kennedy*; Mr. James W. Little*; Mr. James McKechnie; Mr. G. J. Mair; Mr. W. F. Pettigrew, Locomotive Superintendent, Furness Railway; Mr. C. F. Preston,* Town Clerk; Mr. G. Mure Ritchie*; Mr. Councillor J. P. Smith; Mr. Frank Stileman, Engineer-in-Chief, Furness Railway; Mr. Cedric Vaughan; Mr. Walter F. A. Wadham; and Mr. J. M. While.*

Mr. H. Shelford Bidwell; Mr. H. Curson,* Assistant General Manager, Furness Railway; Mr. A. D. Keigwin*; Mr. William Liddle*; Mr. Bell G. Lloyd*; Mr. H. C. Lobnitz*; Mr. C. Mossop, Goods Manager, Furness Railway; Mr. Thomas Partington; Mr. F. J. Ramsden, Superintendent of the Line, Furness Railway; Mr. M. Holroyd Smith; Mr. L. E. Tennent*; Captain Wards, Harbour Master; Mr. Arthur J. While; and Mr. W. S. Whitworth, Resident Engineer, Furness Railway.

The President was supported by the following officers of the Institution :—*Vice-Presidents*, Mr. Bryan Donkin, Mr. Arthur Keen, and Mr. Edward P. Martin ; *Members of Council*, Mr. Henry Davey, Mr. Edward B. Ellington, Mr. Henry A. Ivatt, and Mr. A. Tannett-Walker.

After the usual loyal toasts, the PRESIDENT proposed that of " The Town and Trade of Barrow," and spoke of the town when it was a small hamlet, comparing it with the Institution which started life about the same time. In 1847 the population was about 200, and since then it had grown by leaps and bounds, and wholly on the trade of engineering. Since the last visit of the Institution in 1880, Barrow had wonderfully improved. It had been greatly extended, and the new district of Vickerstown was now being added to the town. One thing in Barrow had not changed since the former visit of the Institution, and that was their hearty hospitality. The toast was acknowledged by the Deputy Mayor, Mr. Councillor CHAPMAN, J.P., who said that Barrow comprised 21,000 acres, of which 11,000 acres were sand and woods. Its success was chiefly due to the engineering and mining industries of the town, and he felt confident that Barrow would never lose its position in the future. The toast of " The Furness Industries" was proposed by Mr. ARTHUR KEEN, Vice-President, who congratulated the Furness Railway Co. on the adoption of the 40-ton cars for carrying iron ore and other materials of that class. Mr. EDWARD WADHAM, J.P., who was the Mayor on the occasion of the last visit in 1880, in replying to the toast, related the progress of the town from 1851 when he was first connected with it.

The toast of " The Reception Committee," proposed by Mr. E. B. ELLINGTON, Member of Council, was acknowledged by Mr. JAMES DUNN, J.P., *Convener*, and Mr. ARCHIBALD MILLER, Honorary Secretary. The concluding toast of " The Institution of Mechanical Engineers" was proposed by Mr. ALFRED ASLETT, and acknowledged by the PRESIDENT.

On Thursday, 1st August, five alternative Excursions were made during the morning.

One was by special brakes to visit the Park Mines of the Barrow Hematite Steel Works, under the guidance of Mr. William Kellett.

Another excursion was made to the Roanhead Mines, near Askam, under the guidance of Mr. Myles Kennedy. The Members then proceeded on colliery trucks to the Askam Iron Works, where a new blast-furnace was put in blast. This visit was under the guidance of Mr. G. Mure Ritchie of the Millom and Askam Hematite Iron Co.

The third Excursion was made to the Barrow Docks, by invitation of the Directors of the Furness Railway Co. and under the guidance of Mr. Alfred Aslett, Secretary and General Manager, and Mr. Frank Stileman, Engineer-in-Chief. Starting from the Devonshire Dock in the steam tug "Furness," the Members and Ladies accompanying them passed slowly through the Devonshire, Buccleuch, and Ramsden Docks, and witnessed the opening of the Michaelson High-Level Bridge.*

Another Excursion was made to the Lindal Mines, near Ulverston, under the guidance of Mr. Frank S. Ainslie, where a large horizontal pumping-engine and sloping shaft were inspected.

A fifth Excursion was made to the Mouzell and Dalton Mines, under the guidance of Mr. G. Mure Ritchie, Chairman of the Millom and Askam Hematite Iron Co.

The Members and Ladies on the foregoing Excursions met at the Furness Abbey Hotel, where they were entertained at luncheon by the Hodbarrow Mining Co., the Millom and Askam Hematite Iron Co., and Messrs. Sir John Aird and Co. After luncheon they proceeded by special train to Millom and thence in contractor's trucks to the Sea Wall and new Outer Barrier. Afternoon Tea was served, and the return journey was made to Barrow.

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* *See* Mr. Stileman's Paper, page 603.

On FRIDAY, 2nd August, two alternative Excursions were made.

One was by invitation of the Directors of the Furness Railway Co. in the new special steamer "Lady Evelyn" to Fleetwood, where the grain elevator and the twin-screw suction-pump hopper dredger of the Lancashire and Yorkshire Railway Co. were visited, by permission of Mr. J. A. F. Aspinall, General Manager, and Mr. W. B. Worthington, Chief Engineer. The Members and Ladies then proceeded by electric trams to Blackpool, by invitation of the Blackpool and Fleetwood Tramroad Co., the Power Station at Bispham being visited on the way. After luncheon at the Hotel Metropole in Blackpool, the return journey was made to Barrow.

An alternative Excursion was made by special train and steamer to Lake Windermere, by invitation of the Furness Railway Co. From Ambleside the visit was continued by special coaches, viâ Clappersgate and Red Bank, to Grasmere, where luncheon was served. The return journey was made to Ambleside by Rydal Water, and thence by special steamer and train to Barrow.

CORPORATION ELECTRICITY WORKS, BARROW-IN-FURNESS.

These works are situated at the north-east end of Buccleuch Street, and are adjacent to the main line of the Furness Railway, being about five minutes' walk from the Central Station.

The buildings comprise an engine room 82 feet in length and 27 feet in width, a boiler house consisting of 2 bays, each 37 feet 6 inches in length and 32 feet 9 inches in width. There are also battery room, test room, stores, &c., on the ground floor, and engineers' offices, &c., on the first floor.

In the engine room the following plant has been installed:—

Three 75-kilowatt high-tension continuous current dynamos, generating at 1,100 volts, coupled direct to 125 H.P. "Universal" engines. Two 150-kilowatt low-tension continuous current dynamos, generating at 250 or 500 volts each, coupled direct to a three-crank 250 H.P. Willans engine. A variable ratio transformer is also placed in the engine room for charging the accumulators. In one bay of the boiler house 3 Babcock and Wilcox boilers, each having a heating surface of 1,218 square feet, are placed, whilst the second bay contains one Babcock and Wilcox boiler, having a heating surface of 2,436 square feet, and also condensing plant capable of dealing with 9,000 lbs. of steam per hour. This plant consists of a Wheeler surface condenser and air and circulating pumps. Two Edward's air pumps and a circulating pump are connected to a common shaft, and are driven by a motor having a double wound armature, so that the plant can be run efficiently at different speeds according to the work which it is required to do. The circulating water is drawn from a large tank, and after passing through the condenser is delivered over a Klein cooling tower, from which it falls into the tank above which the tower is erected. The boilers are fed by two Hayward Tyler 3-throw feed-pumps, and before entering the boilers the feed water passes through a Green's economiser.

The switchboard is placed on a gallery in the engine room, and is so arranged that the transformers, which are placed in the sub-stations, are entirely controlled from the generating station, no attendants being required at the sub-stations. Both the high and low tension mains are of the British Insulated Wire Company's paper insulated concentric type. The distributing mains have been laid on the solid system in V-shaped wooden troughing, and the feeders are drawn into Doulton conduits. The number of 8-candle power lamps or their equivalent connected to the mains now exceeds 16,000; electricity is also being extensively used for motive power, about 30 motors aggregating 160 H.P. being connected to the mains. Mr. H. R. Burnett is the Borough Electrical Engineer.

BARROW CORPORATION WATERWORKS.

The District supplied by the Corporation includes the County Borough of Barrow-in-Furness and the District of the Urban Council of Dalton-in-Furness. In addition to this the Corporation have to supply from their catchment area 400,000 gallons per day as compensation water to the Ulverston Urban District Council, which Council has also a prior claim to an additional 200,000 gallons per day.

The population of that portion of the Water District comprised within the Borough of Barrow-in-Furness has had a very rapid growth, as the following figures will indicate. In 1862 the population was about 3,000; in 1871, 18,911; in 1881, 47,259; and in 1891, 51,712; while at the last census it was 57,589. From present appearances the town is bound to increase very considerably in consequence of the development of the great Naval Construction Works of Messrs. Vickers, Sons, and Maxim, which Company is now building about 1,000 houses and is rapidly covering acres of land with workshops, the firm employing over 10,000 hands, which number will probably be increased as soon as sufficient house accommodation can be obtained. The population comprised within the district of the Dalton-in-Furness Urban Council is about 13,000 and the population of Ulverston is about 10,000, thus bringing up the total population supplied from the works of the Corporation to about 81,000.

The supply is now obtained from three watersheds situated about 7 or 8 miles to the north-east of the town, Plate 157. In these watersheds are situated the following impounding reservoirs having a total capacity of 560,400,000 gallons: namely one, called the Harlock Reservoir, which has a capacity of 226,000,000; another, called the Poaka Beck Reservoir, which has a capacity of 190,300,000; and a third, called the Pennington Beck Reservoir, which has a capacity of 138,700,000 gallons. There are also two small impounding reservoirs near the above at Ireleth, which have a capacity of 5,400,000 gallons. These reservoirs receive the water off an area of about 2,000 acres, situated on the Upper Silurian formation. The level of this catchment area varies from about 500 feet to 1,000 feet above Ordnance datum. Most of the gathering ground is composed of waste moorland, and, speaking in general terms it may be said, that, considering the character of the gathering ground, peat is not abundant. The vegetation consists largely of rough pasture grass, while heather may be said to be abundant on the higher slopes of the hills. The water draining from the gathering ground has a fairly rapid fall, so that hardly any opportunity exists for the rain to stagnate in the peaty soil and so become discoloured.

In addition to the impounding reservoirs above mentioned the Corporation have three service reservoirs, namely, one at Dalton having a capacity of 230,000 gallons, a high-service reservoir at Barrow having a capacity of 3,100,000 gallons, and a low-service reservoir, called the Long Reins Reservoir, having a capacity of 8,500,000 gallons; the total capacity of these service reservoirs is 11,830,000 gallons, thus making the total storage capacity of all the Corporation reservoirs equal to 572,230,000 gallons. The average rainfall on the above watersheds is 51·7 inches per annum, while the average of the three driest consecutive years is about 41 inches. From this it is estimated that the available supply during those years is, after making the usual deductions, about 3,500,000 gallons per day, of which 400,000 gallons are supplied to Ulverston.

The quantity of water supplied for domestic consumption is 21·4 gallons per head, while that supplied for trade consumption is 22·1 gallons per head, the total being 43½ gallons per day per head of the population. The whole of the water is filtered before it is delivered for consumption.

The following is the late Dr. Tidy's analysis of the water:—

The results are stated in grains per Imperial Gallon of 70,000 grains, the Organic Carbon and Nitrogen being stated in parts per 100,000.

Total solid matter.	Ammonia.	Nitrogen in Nitrates and Nitrites. — Nitric Acid.	Oxygen required to oxidise the organic matter.	Organic carbon.	Organic Nitrogen.
Grains.	Grains.			Part per 100,000.	
		Grains — Grains.	Grains.		
8·00	0·003	None.	0·052	0·142	0·020

Lime (CaO.)	Magnesia (MgO.)	Sulphuric Anhydride. (SO_3.)	Chlorine — Common Salt.	Hardness.		
				Before Boiling.	After Boiling.	
Grains.	Grains.	Grains.	Grains—Grains.	Degrees.	Degrees.	
1·95	0·590	trace.	1·008—1·652	4·0	3·8	Silica 0·20 Clear.

Mr. W. H. Fox is the Borough Engineer and Surveyor.

BARROW SEWERAGE WORKS.

The Borough of Barrow-in-Furness has an area of about 21,000 acres and a population of 57,589, residing in 9,760 houses, the average per house being 5·9 as compared with an average of 4·9 only in twenty-five other county boroughs, many of which are situated in the County of Lancaster.

The average rainfall at Barrow is about 38 inches, and of this 55 per cent. falls between 9 p.m. and 9 a.m. and the remaining 45 per cent. between 9 a.m. and 9 p.m.

The sewerage of the town is chiefly carried out on what is known as the duplicate system, the area of the town on this system being about 640 acres, which area may be said to be bounded by the Docks on the south, the Steel Works on the west, Devonshire Road, Ainslie Street, Settle Street, and Windsor Street on the north, and a contour or watershed line which includes a small area of the loopline of the Furness Railway between Abbey Road and Greengate, and then passes eastward so as to include Davy Street, Leicester Street, and St. Luke's Street. All the remaining drainage area of the town outside and north-east of the above is drained by what is known as the high-level intercepting sewer, on the single system, or what is now often called the combined system of sewerage, that is, the sewage and rainfall are designed to be carried off by the same system of sewers. This area is situated at such a level as to be capable of being drained by gravitation in such manner that its outfall sewer may be said to be practically free from tidal influence.

Of the 640 acres above-mentioned as being carried out on the duplicate system, 400 acres have the rainfall drained by a sewer discharging near to the Devonshire Dock Basin. This outfall sewer is capable of discharging with a free outlet a flow off the 400 acres of town area which drains to it a quantity equivalent to a depth of one-tenth of an inch of rain per hour, or 2·40 inches in twenty-four hours. It is estimated that, in order to produce such a flow off the ground, 4 inches of rain must fall in the twenty-four hours, because a considerable percentage would be lost by absorption, evaporation, and percolation. The amount of percentage of course depends upon the time of year, the rate of fall, and the nature of the surface upon which the rain falls.

The rainfall from the remaining 240 acres is drained by a sewer known as the Cavendish Dock Outfall Sewer which discharges at a point about 380 yards south of the powder magazine. This outfall sewer is capable of carrying off a flow from the ground of one-eighth of an inch of rainfall per hour, equivalent to nearly 5 inches of rainfall in twenty-four hours after allowing for absorption and evaporation.

The sewage discharged from the dwellings on the 640 acres is, with a certain percentage of rainfall, conveyed by a sewer to the pump wells of the Sewage Pumping Station at Salthouse, and is there raised by pumping power into the above-mentioned high-level intercepting sewer. The first mentioned sewer is capable of discharging from 9,000 to 10,000 gallons per minute.

Of the 240 acres from which the surface water is drained by the Cavendish Dock Outfall Sewer, there are no less than 25 acres below the level of average spring tides, and some of this area is as much as 8 feet below the highest recorded tide, while the invert of the surface water sewer at Frederick Street situated in the above area is no less than about 20 feet below such highest recorded tide.

All the sewers are ventilated by manholes placed about 100 yards apart, and by ventilation pipes carried up the backs of all houses, which also ventilate the house drains. The total length of sewers in the borough is about 80 miles.

At the sewage pumping station there is a pair of Wolff compound engines, having high-pressure cylinders 12 inches, and low-pressure cylinders 20 inches in diameter. The length of stroke is 39 inches, the pumps are four in number, single-acting, diameter of rams 30 inches, and speed of pumps 8 strokes or 80 feet per minute, delivery per stroke of each pump 150 gallons. The engines and pumps when working together at an average speed raise about 3,000,000 gallons of sewage an average height of 25 feet in ten hours. There is also an engine and centrifugal pump by Messrs. Drysdale and Co., of Glasgow, capable of raising about 4,000 gallons per minute. The boilers, two in number, are of the Lancashire type, about 28 feet in length and 7 feet in diameter.

The attention paid to the sanitary condition of the town by the Corporation is shown by the decrease in the death rate during the twenty-one years given over:—

Year.	Death-Rate.
1879	22·84
1880	19·20
1881	18·50
1882	18·80
1883	17·10
1884	14·30
1885	15·90
1886	15·30
1887	14·50
1888	14·10
1889	16·60
1890	16·40
1891	17·40 (Influenza epidemic.)
1892	15·40
1893	16·70
1894	13·70
1895	13·40
1896	13·40
1897	14·50
1898	14·30
1899	14·10

MESSRS. VICKERS, SONS AND MAXIM, NAVAL CONSTRUCTION WORKS, BARROW-IN-FURNESS.

The Shipbuilding Yard and Engineering Works, which were incorporated on 18th February 1871, were purchased by Messrs. Vickers, Sons and Maxim in 1897, and comprise over 80 acres in area, Plate 96. The Works are laid out on one of a group of islands lying off the peninsula of Furness, the channel which formerly separated the island from the mainland forming now a chain of docks, and one of these, contiguous to the engine works, makes an admirable fitting-out basin. The Walney Channel on the seaward side forms a capital launching area.

Shipbuilding Department.—Entering this department by the main gateway, a turn is taken to the left, passing the general offices and stores, and the Boat-Building Shed is entered, where several small boats may be seen in the course of construction for the war vessels in the dock. Then are entered the Spar and Block Makers' Shop and moulding loft, which are equipped with the various appliances necessary for that work. Going further through, the Joiners' Shop is seen, where all the latest wood-working machine-tools are in use. In this shop the refuse from the machines and benches is swept into pneumatic piping and delivered to boiler fires. Going round the end of the joiners' shop to the shipyard department the electric power station is next visited, where 5 high-pressure engines and dynamos of 250 H.P. each generate the power for all the machine tools, cranes, lights, &c., in the yard. On leaving the power house, the shed at the angle smiths' shop is entered, and the scarphing machine, the large horizontal rolls, and several punches for heavy and light work, are passed on the way.

Then the saw mill is visited (where several frame and circular saws may be seen at work), at the end of which is the platform on which the logs are landed from the timber pond in channel. The saw mill is fitted with refuse collectors similar to those in the joiners' shop. Going from the saw-mill platform the Members pass through the yacht shed round the stern of H.M. first-class Armoured Cruiser "King Alfred" in course of construction. The dimensions of this vessel are:—length 500 feet, breadth 71 feet, draught of water 26 feet, displacement 14,100 tons, indicated horse-power 30,000, and speed 23 knots.

Proceeding under the gantry of one of the cantilever cranes used in the building of the vessels on the slipways, the platers' shed is entered, where a large keel-plate bending-machine is placed, thence on to the plate and angle furnaces out to the plate yard where the cantilever yard crane may be seen at work. Going through the shipyard smithy, the various furnaces and hammers are passed, on to the outside yard, where the masts and spars may be seen in course of construction. From the bank in the shipyard extension can be seen the large extent of ground recently added to the yard and the progress that has been made towards increasing the number of building berths. The cantilever crane on this portion of the ground has a clear run of 310 yards, and reaches from boundary fence to top of slope. From this bank a good view may be obtained of

Vickerstown across the channel. This new town is being built by the Company in response to the urgent necessity for more houses for workmen.

Engineering Works.—Proceeding across Ferry Road, the Members enter the Engineering Works by the north gates. The first building on the left is the Test House and Laboratory; and passing by the west end of the Iron Foundry, the buildings on the right are the shell finishing department and smithy, and those to the left comprise the shell department, with electric power house and boiler house. The power is generated by three sets of high-speed triple expansion condensing engines, and dynamos of 750 H.P. each. The air and circulating pumps are placed in the Power House, the condenser, which is of the jet type, being outside the building adjoining the cooling tower. The boilers are of the Lancashire type, working at 180 lbs. per square inch, and are fitted with mechanical stokers, coal conveyers, and ash conveyers. Economisers have also been adopted, and the products of combustion are taken off by a steel chimney 150 feet high. It will be noticed that provision has been made for adding two more sets of engines and dynamos when required. On leaving the electric power house the Members pass by the south side of the "pond" to the tube staving shop, where the operation of staving or enlarging the ends of boiler tubes for screwing may be witnessed; passing through, the galvanising shop is reached, where various articles in the different stages of the process may be seen. The Iron Foundry which comes next is arranged on the most modern plan, with a view to expeditious and economical working. The building in course of construction on the left in leaving the Iron Foundry is the Field Carriage Shop, and when completed will cover an acre of ground. The next place of interest is the brass and bronze foundries, where all castings of special mixtures, as used in Admiralty engine and gun mountings work, are made. The steel foundry is worked on the "Tropenas" system; and it will be noticed that this building has been made with a view to further extensions. On going to the boiler-making and ordnance-plating shop, the pattern shop, which is fitted with the latest types of wood-working machinery, is seen on the left. In the boiler shop the chief point of interest will, no doubt, be the Belleville Boiler; here can be seen the whole detail and finished boiler, and also the method of construction. The boiler shop, the south portion of which is devoted to ordnance plating, has an area to itself of 242 feet by 163 feet, and the arrangement of tools is such that the steel and iron are taken in at the south end and passed out at the north end a complete boiler, ready for shipping on board a vessel. On leaving this shop will be observed on the right the engineering drawing offices. The tracing department is situated on the upper floor of the adjoining offices.

The Members now proceed to inspect the Floating Dock, an ingenious and useful plant, capable of not merely raising a vessel on it, so that repairs may be carried out, but of depositing the vessel on a grid-iron or stage on shore, and thus becoming available for lifting another vessel, while yet the first ship is being repaired. Attention may be called to the old greyhound of the Atlantic, the s.s. "Alaska," lying close to the Floating Dock. Here is an example of the resources of the firm, who purchased the above to provide a boarding establishment for workmen, there being a great scarcity of houses in the town at that period, but with the advent of Vickerstown this will soon become a thing of the past.

Walking along the quay side of the Devonshire dock towards the 120-ton crane, will be seen the Imperial Japanese battleship "Mikasa," together with His Majesty's cruisers "Hogue" and "Euryalus," which are being completed.

The Gun Mountings department contains almost every type of the most modern machine; and an idea of the amount of work that the firm have in hand will be evident to all. Passing through the brass finishing shop, one arrives at the engine shop, where may be seen the various details of the engines under construction, and the general arrangement of the erection pits. The engines in the pits are for His Majesty's first-class cruiser "King Alfred," and are designed to develop 30,000 horse-power with the two sets. On leaving the Engine Shop by the east door and turning to the right, the Members arrive at the main entrance to the Engine and Gun Mountings Department, from which their departure is made. Mr. Thomas E. Vickers, C.B., M. I. Mech. E., is the Chairman of the Company. The number of men employed is over 10,000.

FURNESS RAILWAY LOCOMOTIVE, CARRIAGE, AND WAGON WORKS, BARROW-IN-FURNESS.

These works, founded in 1846, are situated in Barrow, Plate 156, and have the same entrance as the general offices of the company, with a frontage in St. George's Square. They occupy an area of about thirty acres. The first locomotive fitting shop and running shed is now the machine shop and turnery, in which are the wheel lathes, planing, slotting, drilling and other machines. The power for driving this shop is obtained from two small horizontal steam-engines, the various cross-shafts being driven by means of bevelled gearing with the exception of one driving the cross shop, this being driven by means of cross belts. Adjoining this is the smiths' shop, with fifteen smiths' hearths, and with a furnace for heating the tyres for locomotives, carriages, and wagons. All the smoke from the plate and forge furnaces, stationary boilers, and smiths' fires, leads through an underground flue into a large chimney shaft, which stands outside the works in the middle of Salthouse Road. The boiler shop contains a 15-ton overhead travelling-crane, steam punching-machine, bending rolls, &c. Adjoining this is the boiler house containing three Galloway boilers working at a pressure of 50 lbs. per square inch for supplying steam for the shop engines, steam hammers, and other appliances.

The second running shed is now the erecting shop, which, owing to its low roof, has no overhead crane, the engines having the wheels taken from them and replaced by means of dropping pits. This shop consists of three bays, each 30 feet span by 160 feet in length. It contains six roads, with engine pits accommodating four engines on each road. Adjoining this shop are the spare gear stores. Beyond this is the Locomotive Superintendent's office, running department, and drawing offices, the latter being on the upper storey on the same floor as the pattern and joiners' shop. The present running shed is a stone building 310 feet in length by 150 feet in width, and capable of holding sixty engines. Close to the engine shed is the new shed for coaling engines on the high level system. There are two platforms, the coal wagons being in the centre, and the incoming roads being at each side, enabling four engines to be coaled at one time. Beyond the sheds and between the roads is the ash-bin, with pits at each side for the driver to examine his engine whilst the fire is being withdrawn.

The carriage and wagon shops are at present being enlarged. The wagon shop is 300 feet in length by 160 feet in width, and consists of a carriage body shop, carriage underframe, wagon building, smiths', wheelwrights', and machine shops, and saw-mill. The carriage paint-shop is 195 feet in length by 40 feet in width, but a new and larger shop is being constructed, capable of holding twenty carriages. There is also a wagon-repairing shop and a timber drying-shed. The carriage sheds, four in number, are situated near the Barrow Central Station, and can hold 152 carriages. In addition there is a shed for holding the saloon carriages. All the carriages on this railway have the bodies painted ultramarine blue with white upper panels, and the locomotives are coloured a rich indian red. Passenger brake-vans have also been specially fitted to facilitate the conveyance of bicycles.

A large number of the goods and mineral vehicles are of the bogie type, some of which are 40 feet length, and, whilst only weighing 10 tons, are capable of carrying 30 and 40-ton loads, the ratio being as low as 20 per cent. of dead weight to carrying load. Some of the recent wagons have been constructed of pressed steel for carrying iron ore. The company has now 130 engines, 376 carriages, and 7,598 wagons.

The first locomotive superintendent of the Furness Railway was the late Sir James Ramsden, who was a Vice-President of this Institution from 1889 to 1896. He was followed by Mr. Richard Mason, who retired in 1897, and was succeeded by the present locomotive, carriage, and wagon superintendent, Mr. W. F. Pettigrew, M.I.Mech.E.

BARROW FLAX AND JUTE WORKS, BARROW-IN-FURNESS.

These works of the Barrow and Calcutta Jute Co., whose head offices are in Liverpool, occupy about 12 acres, with frontages to Hindpool Road, Ramsden Square, Abbey Road, Duke Street, and Clive Street, and have a private siding to the Furness Railway. The offices and main entrance are in Hindpool Road. The works are principally engaged in the spinning of jute yarn and in the manufacture of jute goods, including bags for sugar, flour, grain, coffee, wool, cotton, chemicals, &c.; also fabrics for linoleum, floorcloth, packing and general purposes.

The raw jute is imported in bales from Calcutta, and stored in the company's warehouses and in the jute warehouses at the Devonshire Dock. In the spinning sheds it passes through the various machines for softening, carding, drawing, roving, spinning, spool and cop winding, &c. The yarns then pass into the beaming sheds, and thence to the weaving departments where they are made into fabrics of various weights, texture, and widths. After leaving the weaving sheds, the cloth passes through the inspecting room, where it is measured, weighed, and examined. It then goes into the cloth-finishing department, where it is cropped, calendered, mangled, lapped or put into large rolls, or press-packed into bales for shipment or for home consumption. The fabrics for bag making are drawn up into the floors above by the cutting machines, which, at the same time, cut them into the various lengths required; the latter are sewed by sewing machinery into sacks and bags, with tarred or dry twine. The bags are then marked by printing machinery, after which they are folded and made up into bundles.

These works are at present on a smaller scale than formerly, as the portions destroyed by fire some time ago have only yet been partially rebuilt. In the reinstatement of the portion referred to, however, every advantage has been taken of the opportunity to introduce all the best and latest improvements in the trade.

THE BARROW SALT CO.,
WALNEY ISLAND, BARROW-IN-FURNESS.

The extensive and valuable salt deposits in the Island of Walney were first discovered in 1889. Boring operations for coal, by the Diamond Boring process, were being carried on a short distance to the south of the village of Biggar, Plate 157, when, underlying about 140 feet of red and blue marl with gypsum, a bed of rock salt was unexpectedly met with at a depth of about 272 feet from the surface. The area of the deposit was afterwards absolutely proved by a series of bore-holes to extend for 6 miles in length, and for a distance of 3 miles the thickness of the rock salt was found to range from 72 feet to 446 feet. The depth from the surface to the top of the salt varies from about 90 to 120 yards. One of the borings was carried down to a depth of about 1,000 feet from the surface in red, blue, and green marls with beds of rock salt of variable thicknesses, and at irregular distances apart.

In 1896 the Barrow Salt Co. was formed, with a capital of £100,000, for the purpose of working and developing the property. Four bore-hole wells were put down about half a mile to the south of the village of Biggar, and fitted up complete with derricks, engines, boilers, pumps, etc., by Vivian's Boring and Exploration Co. The wells average about 500 feet in depth, and are lined with wrought-iron tubes 10 inches in diameter until the salt bed is reached at an average depth of about 100 yards from the surface.

The engines and pumps are of the same pattern, and all the working parts are interchangeable. The pumps are 6½ inches diameter, and the length of stroke can be varied from 1 foot 8 inches to 4 feet. Each pump, working for twelve hours a day, is capable of pumping 300,000 gallons of brine per week, which is equivalent to about 300 tons of manufactured salt. A small experimental plant has been erected at the wells for the manufacture of salt by means of the exhaust steam from one of the pumping engines, but owing to the process being necessarily intermittent the results obtained are not so satisfactory as would otherwise be the case. Natural brine was met with from the first, but the supply not being sufficient for the requirements of the works, it became necessary to supplement it by passing fresh water down the wells from the water-bearing strata met with in carrying out the boring operations. The brine thus obtained is of good quality and of full saturation.

From the pumps the brine is conveyed in 9-inch cast-iron pipes a distance of three-quarters of a mile to the settling tanks and filter beds; and the filtered brine, from which all matters in suspension have been removed, then flows into a storage reservoir immediately adjoining, and having a capacity of about 700,000 gallons. The level of the storage reservoir is so arranged that the brine feeds the evaporating pans at the works by gravitation through 9-inch cast-iron pipes about $2\frac{3}{4}$ miles in length, and the supply of brine into the pans can therefore be regulated at the works by the men in charge of same.

The evaporating plant is situated near the extreme south end of Walney Island and within 4 miles from the main entrance to the Barrow Docks. This site was selected because of the unusual facilities which it offered for the cheap erection of the necessary buildings, etc., owing to the unlimited supply of sand and shingle for making concrete, and also for the convenient shipment of the manufactured salt.

The works comprise one range of twenty pans for the manufacture of common salt, and one of four pans for the manufacture of lumps and fine butter salt. The twenty-four pans are of the same dimensions, namely, 64 feet long by 24 feet wide by 2 feet deep, and can, when occasion arises, all be utilised for making common salt. When lump or butter salt is being made a wooden mid-feather is fixed across the pan about 40 feet from the fire-place end, and the other portion of the pan is used for making common salt. The twenty common pans are arranged back to back under one roof in two parallel rows of ten each with a chimney 120 feet in height to every four pans. The quantity each pan is capable of turning out is from 50 to 55 tons of common salt per week. Each of the lump pans is capable of turning out about 50 tons of lumps and 10 tons of common salt per week. The four lump pans are under one roof, and the flues, after passing under the pans, are carried through the hot-house where the lumps are stoved and stored ready for shipment. There is a store capable of holding about 600 tons of lumps above the hot-house. Coal depôts, capable of holding about 5,000 tons of coal, are conveniently arranged in front of the fires. There are two large stores, one on each side of the range of common pans, with a total storage capacity of about 10,000 tons.

The town water has been brought down to the works for boiler and domestic purposes, but there is an ample supply suitable for purposes in connection with the manufacture obtained from a well on the premises, and pumped by means of a windmill into a large tank from which it gravitates to all parts where it is required. The works are connected with the shipping wharf, which is only about 400 yards distant, by means of a narrow-gauge tramway. The depth of water at the wharf is 22 feet 6 inches at ordinary spring tides and 15 feet at ordinary neap tides, and steamers carrying 800 tons have been alongside the wharf for the discharge of cargo.

BRITISH GRIFFIN CHILLED IRON AND STEEL CO., BARROW-IN-FURNESS.

These works are situated near the Central Station of the town. The firm is a modern example of British manufacture on American lines and system, whereby the many needs of electrical tramways in Great Britain and Ireland can be met as regards specially suitable wheels, hitherto manufactured in large quantities in the United States.

The Company has acquired from the New York Car Wheel Company their interests and system of manufacture in Great Britain, Ireland, India, and all the Colonies, with the exception of Canada. Under this system some millions of wheels have been made and are running in the United States of America under locomotives, passenger cars, and goods wagons, etc. This system is also in extensive operation at the following works:—Messrs. Ganz and Company, Budapest; Société Française Metallurgique, Griffin, Gorcy; Fried Krupp, Magdeburg; Griffin Metallurgetschiski Zavod, Odessa; Société Belge Griffin, Merxem-lez-Anvers; and Société Italiana Franchi Griffin, Brescia.

The works at Barrow-in-Furness are equipped with the most complete and modern plant for the manufacture of railway and tramway wheels, and include a fine bay and overhead girder electric crane track for special heavy chilled work, with an electric crane running the whole length of the foundry commanding one half side, the other half being the moulding and casting floors which are fed and actuated by compressed-air cranes suitably placed on each separate wheel floor.

The processes run in one continuous line throughout, from the melting room at one end of the foundry to the machine-finishing shop at the other end, where the wheels and axles after completion are examined, paired, and fitted, and placed into the railway trucks.

The works commenced operations in April of the present year, since which time many thousands of wheels have been manufactured for tramways in this country; orders have also been executed for the Indian States Railways, Assam-Bengal, Rhodesia, Tasmania, and the British North Borneo Railways, and an order for H.H. The Nizam's Guaranteed States Railway is now passing through the shops.

FURNESS BRICK AND TILE WORKS, BARROW-IN-FURNESS.

These works were started about thirty-five years ago by Messrs. Woodhouse and Co.; later they passed into the hands of Messrs. R. F. Matthews and Son, and eventually in 1898 the present company was formed, with Mr. R. F. Matthews as chairman and managing director. The company has two large works and premises, one situated at Hindpool covering an area of about

19 acres, and one at Ormsgill of about 6 acres. Both works are completely equipped with the most modern and efficient brick and tile-making machinery, and are in direct connection with the Furness Railway.

The output of the two works comprises all the usual kinds of plain and ornamental bricks, drainage tiles for agricultural purposes, and the best kinds of facing bricks. Both pits have the same kind of clay, which is noted for its weight-supporting qualities and general excellence. The weekly output is about 320,000 common bricks and 53,000 facing bricks. The number of men employed is about 250.

PAPER PULP WORKS,
BARROW-IN-FURNESS.

These works, belonging to the Kellner-Partington Paper Pulp Co., are situated at Salthouse, about one mile from the Town Hall. They were started in 1888 under the title of the Barrow Chemical Wood Pulp Co., for the manufacture of wood pulp for paper-making purposes by the bi-sulphite process. In 1889 they were incorporated in the present company. The site for the works comprises about 15 acres.

Large stocks of pulp-wood are received during the summer months for the year's supply, chiefly from Sweden, Finland, Russia, and Newfoundland; this usually amounts to 20,000 tons. Wood is taken from the stacks on trolleys to the wood-preparing room, where it is sawn, freed from bark and a large proportion of the knots, chopped and elevated to the "digestor" houses. In these houses fourteen spherical digestors of 12 feet diameter, lined with an acid-resisting material, are used to cook the wood chips with a bi-sulphite solution. The chips are heated by steam together with the acid solution to free them from resin and incrustating matter, leaving the cellulose for paper making. The chemical rooms are fitted with a plant for the production of bi-sulphite on Partington's continuous process system, the acid liquors being obtained from recovered sulphur and dolomite lime. In the bleaching rooms the pulp is treated with a solution of chloride of lime, and then stored in large drainers, after which it is dealt with in the ordinary manner. The paper-making plant comprises four large paper-machines with the necessary beating-engines, machine and super calenders, cutters, &c. Two large rooms are used for sorting, finishing, and packing the various productions.

The steam-power plant consists of eight Lancashire boilers, 32 feet by 7 feet 6 inches, and one 22 feet by 7 feet 6 inches, fitted with Green's economizers of 576 pipes. There are four main engines of the compound tandem type, running at 70 revolutions per minute with 90 lbs. steam pressure, and capable of developing 450 H.P. each. The fly-wheels of 18 feet and 20 feet diameter are arranged as belt pulleys, two 48-inch, one 44-inch, and one 40-inch width belts running upon them. There are several small engines driving the various machines and a deep well pump. The water supply for the works is obtained from two wells sunk 450 feet in the red sandstone. The works are lighted throughout by electricity. The number of workpeople employed is about 500.

MESSRS. WALMSLEY AND SMITH, CORN MILL, BARROW-IN-FURNESS.

The Flour Mills of Messrs. Walmsley and Smith are situated on the Furness Railway Company's Dock estates between Hindpool Road and the Devonshire Dock, the two large warehouses for grain storage, etc. (which are connected to the Mill by an overhead bridge), being built directly on the edge of the dock. These mills were built by the old Barrow Corn Mill Company in 1870, but the business not being a success, the mills were leased in 1881 to the firm which now occupies them. Soon after this date Messrs. Walmsley and Smith adopted the new Hungarian roller system, being one of the first milling firms in this country to do so, and entirely dispensed with the use of the time-honoured millstone; since that date, however, great changes have been effected in the milling trade, and the plant has had to be entirely re-modelled several times.

The mill premises now contain two complete and separate flour plants with the total capacity of 3,000 sacks per week, in addition to the usual machinery for the production of provender; most of the machinery is by H. Simon of Manchester, but several of the other milling engineers are also represented. The machinery is driven by a compound horizontal condensing engine of about 400 H.P., which runs continuously from Monday to Saturday without stopping; steam is supplied by three Lancashire boilers 30 feet by 7 feet, working at a pressure of 95 lbs.; one of these boilers is a spare one. The firm have their own electric lighting plant, which, with the exception of the arc lighting at the Ramsden Dock, was the earliest application in the town of electric lighting, and has been running since the beginning of 1885. The warehouses are two commodious buildings connected together with an arcade which is used for the purpose of loading and unloading railway-wagons, and have a total capacity of about 8,000 to 10,000 tons. Grain is lifted off the vessels lying alongside by a series of hydraulic cranes, and is conveyed across the bridge afore-mentioned into the mill adjoining by means of a 12-inch band conveyor. A scheme is now in hand for the erection of a silo adjacent to the present warehouses, which will be fitted with a movable elevator for lifting the grain in bulk in a continuous stream out of the vessels, and storing it in bins on the silo system, which is now more generally adopted.

ASKAM IRON WORKS, ASKAM-IN-FURNESS.

The Askam Ironworks are part of the plant owned and operated by the Millom and Askam Hematite Iron Co., of Millom, Cumberland, Plate 157. It consists of four furnaces—one modern 90-feet furnace, and three older furnaces 75 feet high. The modern furnace, No. 1, was put into blast at about the time of the meeting.

The Askam Ironworks consume material from the following sources:—

Coke is brought exclusively from the Durham district; only the purest and best quality obtainable is used.

Limestone of excellent quality is supplied from the Millom and Askam Company's Goldmire Quarry, situated about 1½ miles from the works, near the line of the Furness Railway. The limestone analyses on an average:—

CaO	53	per cent.
SiO_2	2	,,
P	0·004	,,

Ore is obtained from the following sources:—

(1) *Alquife Mines*, Province Granada, Spain. These mines, with the railways attached to them, are owned in part by the Millom and Askam Co., and constitute one of their most valuable properties. The mines contain a magnificent body of pure, uniform and almost self-fluxing hematite ore. The quantities in sight, or positively ascertained to be available, are fully 20,000,000 tons, in massive bodies located above the level of natural drainage, and the ore is therefore cheaply mined. The ore analyses on an average:—

Fe	47	per cent.
SiO_2	5	,,
CaO	4	,,
P	0·009	,,
Mn	1·5	,,
S	trace.	

The ore is absolutely free from Cu, As, Zn, and Ti. As it in addition contains over 10 per cent. of volatile matter, it is unquestionably one of the best and most valuable ores smelted in Great Britain.

(2) *Askam Mines*, owned in fee by the Millom Co., located not far from the Ironworks. They have for years yielded an excellent quality of pure and clean ore, but the remaining deposit is of small extent.

(3) *Dalton and Mouzell Mines* are operated under lease by the Millom and Askam Co., and are connected with the Askam Works

by the Company's private railway, 2 miles long. Five pits are at present worked. The ore varies somewhat at the different pits, but is always low in P, and free from S, As, and other deleterious elements. Owing to its high percentage of Al_2O_3, the ore is a valuable aid in obtaining the correct composition of the furnace slag.

(A) *Mouzell No.* 1 *pit*—a large deposit of clayey hematite, which has yielded ore for more than twenty years, and which still gives indications of continued output. The known area of the deposit is over 8000 square yards.

(B) *Mouzell No.* 6 is operated from a double shaft sunk in 1900 to a depth of 113 yards. The ore in this pit is very pure and fairly rich. The vein now being worked measures 36 feet in thickness, and is of considerable extent. This pit alone is now in condition for raising a quantity of about 2000 tons per month for an extended period.

(C) *Dalton No.* 4 is a shallow pit which reaches a valuable body of ore notable for being almost self-fluxing. Ore has been broken in this mine for over fifty years, but the deposit does not give promise of any great development.

(D) *Dalton* 14 is a new shaft, at present 51 yards deep, passing through 90 feet of solid ore. A cross drift at a depth of 30 yards extends in ore 85 yards. Another drift at right angles with the first has been driven in ore to a length of 30 yards. The deposit promises to be one of considerable value and extent, and should be worked at the rate of not less than 1,500 tons per month.

(E) *Dalton* 15 is a new shaft which enters a body of ore at a depth of only 10 yards below the surface. The shaft has now been sunk in solid ore to a depth of 40 yards, and cross drifts at this level show the pocket in this plane to measure 43 yards from north to south and 20 yards from east to west. The ore is clean and good.

The percentage of iron in the Mouzell and Dalton ores varies from 40 to 50 per cent.

(4) *Hodbarrow Ore Mine.*—This splendid deposit produces an ore which is unquestionably the richest of all the ores now mined on the north-west coast.

(5) *Furness district ores* are obtained by purchase from mines adjacent to the Askam Works. They are of the same general quality as the Dalton and Mouzell ores.

(6) *Cleator ores* are known for their purity, and also for their high percentage of SiO2, which make them refractory and somewhat wasteful of coke.

The ore mixture available at the Askam Works is as a whole remarkable for purity, and lends itself to the production of low phosphorous Bessemer iron of the highest grade.

The water supply is obtained by surface drainage from the adjacent hills. It is stored in reservoirs covering 10 acres, to which it is returned over and over again after passing the condenser, tuyeres and cooling-boxes. For the latter service, the water is pumped from the reservoirs into a steel standpipe 15 feet diameter, 100 feet high, by compound pumps having a capacity of 2,500,000 gallons per twenty-four hours.

Sand, loam and clay are obtained from the immediate neighbourhood of the works.

Plant.—Materials arrive by rail over the Furness Railway or the Company's own lines. The railway wagons are hoisted 40 feet to the top of the stock house by direct-acting steam lift. They pass along the inclined elevated tracks by gravity, and are lowered at the far end of the stock house by a compressed-air lift. All the limestone and about 75 per cent. of the ore are drawn automatically by gravity from the hoppers into the charging barrows. The coke is directly drawn from the hopper into the skip of the inclined hoist. Only occasional skip loads of coke are weighed to check the charging. Stock is carried to the top of the furnace, distributed on the bell, and charged by an automatic Brown hoist and distributor having a capacity of one ton of coke or two tons of ore per trip. The hoist is capable of making fifty trips per hour, giving a capacity of more than 1,500 tons of material per twenty-four hours. The duplex hoisting engine—14 inches by 18 inches, non-reversing—is fitted with Brown's friction clutch, automatic stops, trip counter and friction brake. The engineer, from his post near the foot of the inclined hoist, operates the bell, sounding rods, and coke hopper, as well as the hoist proper.

The new, No. 1, furnace stack is 90 feet high, 19 feet wide in bosh, 11 feet in hearth, and 14 feet diameter at stock line. It is fitted with a 10-foot bell operated by a 20-inch steam cylinder. The steel shell rests on six cast-iron columns, 26 feet high. There are twelve 5-inch copper tuyeres resting in phosphor-bronze coolers at a height of 7 feet above the bottom of the furnace. Two slag notches with Lürmann's bronze slag tuyeres are located at opposite sides of the furnace. The tap hole is controlled by Vaughen's closing machine, or so-called "Mud Gun," operated by steam. The hearth is girded by a steel casing 1¼ inches thick, 4 feet high, quadruple riveted. Resting on this is the well casing formed of 3-inch cast-iron plates 8 feet high. The tuyeres are held in position by a band of steel casting collars bolted and linked together. The bosh, which slopes at an angle of 74°, is cooled by nine rows of phosphor-bronze and pipe coil cooling plates. All pipe connections around hearth and bosh are made by 1¼-inch piping. The hot-blast valve is operated by steam. The furnace stands 14 feet above the general track level, permitting the slag to be drawn off in Weimer slag gondolas of 200 cubic feet capacity. The metal passes across the bridge spanning the slag tracts on to the spacious casting beds, where it is run into moulds in the ordinary manner. When cold, the pig beds are lifted whole from the sand by a Morgan electric crane of 10 tons capacity, running at a speed of 450 feet per minute over the elevated tracks covering the casting beds, pigbreaker, and storage yards. The pig beds are either classified according to chemical composition, and stored whole until required for shipment, or they are directly placed on the feed table of the pigbreaker to be broken up and shipped.

The pigbreaking machine is of the Martin and James type, having four cylinders, No. 1 breaking 4 pigs at the centre, No. 2 clamping the pig bed to the anvil, No. 3 breaking the sow, and No. 4 moving the bed forward from the feed table. The machine has a proven capacity of fully 60 tons per hour. It is supplied with filtered water under a pressure of 1,000 lbs. per square inch from a duplex plunger packed Worthington pump having a capacity of 40 gallons per minute, assisted by a direct-acting accumulator 8 inches diameter by 11 feet 6 inches stroke. The blast is heated in four firebrick stoves. Two of these are Cowper stoves, measuring 21 feet in diameter and 90 feet high. The remaining two are of the Ford and Moncur type measuring 26 feet diameter by 70 feet high. The gas is led to the stoves and boilers through a downcomer 6 feet 6 inches in diameter, entering tangentially into the cylindrical dustcatcher, which measures 15 feet in diameter by 50 feet high. It is distributed through a horizontal overhead gas-pipe 7 feet in diameter. The top of the furnace, downcomer, dustcatcher and gas mains are all liberally equipped with automatically opening doors to minimise the dangers from slips or explosions.

Boilers.—Steam at 150 lbs. pressure is generated in four batteries of Babcock and Wilcox boilers, each rated at 500 H.P. The boilers will readily evaporate 90,000 lbs. of water per hour.

The draught stack is 326 feet above the ground level, and has a smallest inside diameter of about 16 feet. It produces a draught of about 2¼-inch water column.

Blowing Engines.—Besides three old-fashioned upright engines kept as a reserve, the new furnace will depend on one modern steeple-built cross-compound condensing engine, constructed by Messrs. Galloways of Manchester, to the specifications of the Millom and Askam Company. The engine is of the cross compound type, having cranks coupled at 90°. The steam cylinders are 42 inches and 80 inches diameter respectively; and the two air cylinders are 84 inches diameter, all 60 inches stroke. They are suitable for working with 125 lbs. steam pressure, and are designed to blow an air blast of 20 lbs. The distribution of the steam to the high-pressure cylinder is by Corliss valves, having separate eccentrics to steam and exhaust. Automatic expansion is provided on the high-pressure cylinder by a powerful governor, having special arrangement for closely regulating the speed of the engine at any point between wide limits. The point of cut-off in the low-pressure cylinder, which has piston-valves, is adjusted by hand. The air cylinders are provided with grid-valves of the "Southwark" type, with the necessary gear for their mechanical operation. This arrangement gives the smallest possible clearance, not exceeding $1\frac{1}{2}$ per cent. The total weight is 330 tons. When running at fifty-five revolutions, the engines will deliver over 40,000 atmospheric cubic feet of air per minute. The condenser is built by Messrs. A. Barclay, Sons and Co. of Kilmarnock. It is of the Edwards type, having three air pumps 38 inches diameter with a stroke of 16 inches. The steam-engine is compound, 16 inches high-pressure cylinder, 30 inches low-pressure cylinder by 18 inches stroke. The speed of the engine is automatically regulated by the vacuum. The electric plant consists of one set of Browett, Lindley and Company's 50-kilowatt high-speed compound engines and dynamo, which drives the pigbed crane, electric lights, and smaller motors for various purposes.

The number of men employed in the various works and mines of the Millom and Askam Co. is about 800. Mr. A. Sahlin is General Superintendent.

BACKBARROW IRON WORKS, NEAR HAVERTHWAITE.

These now consist of one Charcoal Iron Furnace, and are built entirely of stone, and bear the date of 1710. It is the last of five at one time worked by Messrs. Harrison, Ainslie and Company (the others being at Bonawe, Argyleshire; Duddon Bridge, Cumberland; Warsash, Southampton; and Newland, near Ulverston), and is the only furnace in this country that produces charcoal pig-iron. The fuel is obtained from the woods in the neighbourhood. The blast is cold, and is blown by water-power from the River Leven upon which the works are situated. The production is from 30 to 35 tons per week, but the furnace is at present out, and will not be put into blast until the end of August 1901.

HODBARROW IRON ORE MINES, MILLOM.

These mines, Plate 157, were first discovered about 1845 through the occurrence of veins of ore in the carboniferous limestone which forms the rocks on the shore at Hodbarrow Point. The late William, Earl of

Lonsdale, worked one of these veins by means of an adit level from the shore, but meeting with little success he gave up the venture, and granted a "take note" to the founders of the Hodbarrow Mining Co. in 1855. A shaft was sunk on the same vein, and the shaft and engine-house are still visible on the top of the hill at Hodbarrow Point. As the vein was followed it began to nip out, and boring was resorted to. The late Mr. William Barratt observed that the veins converged towards the west, and, putting down a bore-hole at the probable point of intersection, proved 100 feet of solid hematite ore, and so discovered the first deposit in 1856. This deposit yielded excellent ore, and while the Company were working it they built workmen's houses on the adjoining mains without knowing what was beneath them. While sinking a well to supply these houses with water, another large deposit was found by means of a bore-hole put down at the bottom of the well with the view of increasing the water supply. This led to other borings in the vicinity, when it was found that a very large deposit of ore existed under the Hodbarrow Mains.

The first discovered deposit was comparatively shallow, with not more than 60 feet of cover over it at any part, and in one place it came almost to the surface. Between this deposit and the larger one was an intermediate deposit of smaller area, which overlapped the large or main-deposit, this last named lying much deeper and having a cover about 200 feet thick. The first and second deposits are practically worked out, and it is the larger or main-deposit which is now being worked. The Company's first lease of the minerals only extended to ordinary high-water mark on the south, and ore was proved to exist right up to this boundary. But inasmuch as the surface caved in when the ore was extracted, it was necessary to leave a barrier of ore 360 feet wide to protect the mines from the sea, which otherwise would have filled the hollows on the surface and eventually have flooded the mine as well. This barrier was ultimately found to contain over five million tons of ore, and to enable the Company to win this, a sea wall was erected in 1890 to exclude the sea from the foreshore immediately in front of the mine. Sir John Coode was the engineer, and it was the last work he finished just before his death. It was a novel piece of engineering, being a combination of a sea wall and a water-tight dam.

The Earl of Lonsdale then gave the Company rights to search for ore under the foreshore seawards, and after boring for some years under considerable difficulty, owing to the heavy seas which frequently washed away the stagings and gear, it was satisfactorily proved that the main deposit of ore extended not only under the old high-water mark but also under the sea wall, and to a distance of some 500 yards beyond it. The full extent of this ore ground has not however even yet been fully proved.

The second sea wall, or "Outer Barrier" as it is officially termed, will enclose an area of 170 acres, and when completed it will enable the Company to win the ore under the foreshore, which could not otherwise have been worked with safety. The mine, which is liable to inrushes of sand and water from the cover, is drained by three Cornish pumping-engines, each having a cylinder 70 inches diameter by 9 feet stroke. One of these engines works a plunger 25 inches diameter by 10 feet stroke, the other two each work a pair of 18-inch plungers by 10 feet stroke, all from a depth of 50 fathoms with bucket lifts from 60 fathoms up to the 50-fathom level. As a general rule one of these engines is sufficient to keep the mine drained, but when a run of sand occurs it takes two and sometimes all three of them to contend with it. The plungers lift sand and water with ease so long as the sand is kept in a fluid state, and this is effected by taking a jet of fresh water down from the surface and discharging it into the sump, which, acting under a head of 300 feet, keeps the sand in the sump in such a condition of fluidity that the plungers lift it without difficulty; and should the sand during a temporary stoppage settle in the pump column, the door of the top clack is removed, the jet is turned up the column, which quickly clears it of sand, the door is then replaced, the column is filled with fresh water from the top, and the engine goes to work again at once.

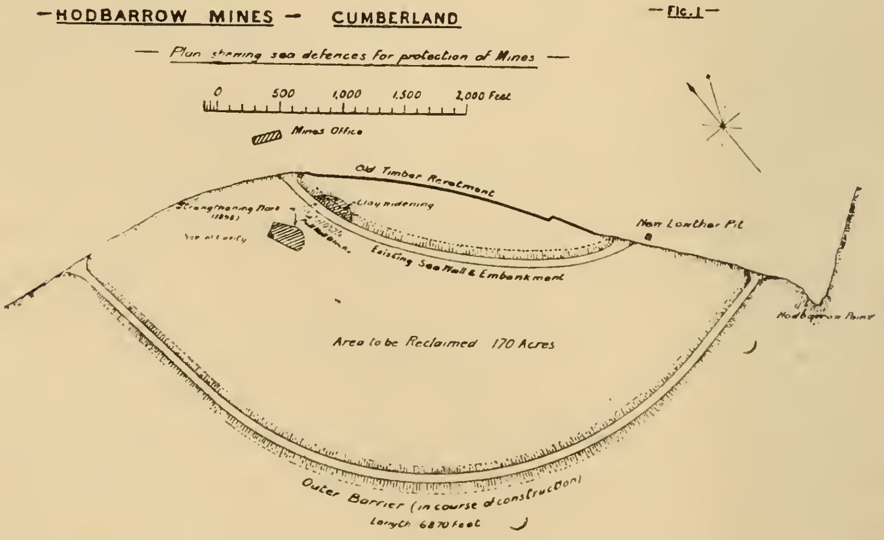
The winding engines are direct acting. The last new one was made by Messrs. Walker Brothers of Wigan, and has two cylinders, each 24 inches diameter by 4 feet 6 inches stroke, with 11 feet drums. Messrs. Coode, Son, and Matthews are the engineers for the Outer Barrier, and Messrs. John Aird and Co. are the contractors.

SEA WALL AND EMBANKMENT WORKS, AT THE HODBARROW MINES.

Mr. WILLIAM MATTHEWS being prevented through illness from writing the Paper which he had promised for this meeting, descriptive of the sea works designed by his firm for the protection of the Hodbarrow Mines, has asked the writer, Mr. Cedric Vaughan, Managing Director of the Mines, to prepare a short description, which he has great pleasure in doing, with the able assistance of Mr. H. Shelford Bidwell, the Resident Engineer to Messrs. Coode, Son and Matthews, of the Outer Barrier Works now in progress.

Mr. Matthews desired the writer to express to the President and Members of the Institution the great sorrow he felt at being deprived of the pleasure of meeting them at Millom, and accompanying them over the works now in progress, a pleasure to which he had looked forward in no small degree in view of the very exceptional character of the structures designed and carried out by his firm of Messrs. Coode, Son and Matthews at these mines.

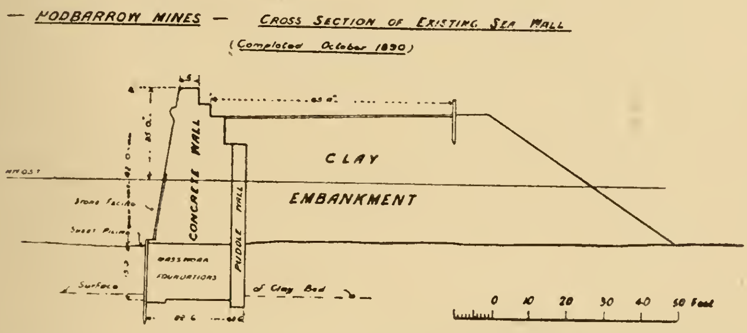
The late Sir John Coode advised the Hodbarrow Mining Company as long ago as 1865 respecting their harbour in the Duddon estuary, and was subsequently consulted by them on several occasions in matters


—HODBARROW MINES — CUMBERLAND
—FIG. 1—
— Plan shewing sea defences for protection of Mines —
0
500
1,000
1,500
2,000 Feet
Mines Office
Old Timber Revetment
Clay widening
Strengthening Work (1898)
New Lowther Pit
Existing Sea Wall & Embankment
Hodbarrow Point
Area to be Reclaimed 170 Acres
Outer Barrier (in course of construction)
Length 6870 feet

connected with pier construction and sea defence. It was while Sir John Coode was in Australia many years ago that Mr. Matthews advised them with regard to the strengthening of the timber revetment shown on Fig. 1 (for the design of which by the way his firm were in no way responsible), and which had been breached by the sea during an exceptionally heavy storm.

Subsequently, about the year 1885, Sir John Coode and Mr. Matthews designed the existing sea wall and embankment, the object of which was to exclude the sea from a sufficient area of the foreshore to enable the company to win the ore up to high water mark, which was the boundary of their lease at that time. This sea wall is a rigid structure of concrete, backed by a clay embankment, and rendered water-tight by a trench of puddled clay pinned into the clay bed beneath, Fig. 2. It was most efficiently constructed by the firm of Messrs. Lucas and Aird as contractors, has proved itself to be absolutely sea-proof and water-tight, and has enabled the company to win several million tons of ore which could not otherwise have been worked.

— Fig. 2 —



In the year 1898, a bed of quicksand was tapped in the mine, which established a connection between the sea and the underground workings, a cavity being formed on the outer foreshore, Fig. 1, and a heavy rush of tidal water into the mine took place, passing many fathoms below the foundations of the sea wall. This, however, was promptly checked by filling up the cavity on the shore with furze and clay, but not before the sea wall showed signs of distress through deflection caused by the undercurrent of tidal water into the mine.

The clay embankment behind the wall subsided about 5 feet, and this subsidence had the effect of shutting off the connection with the sea, and the influx of tidal water shortly after ceased. Mr. Matthews having been called in, advised that the sea wall would stand provided it were not exposed to heavy strokes from the sea, and he designed a wave-breaker of pell-mell blocks of concrete (20 tons each) Fig. 1, which was placed in front of the damaged wall and which has effectively protected it from sea action. He also not only levelled up the subsided embankment, but added to it also both in height and width so as to give additional weight, and thus aid in shutting off the leakage into the mine.

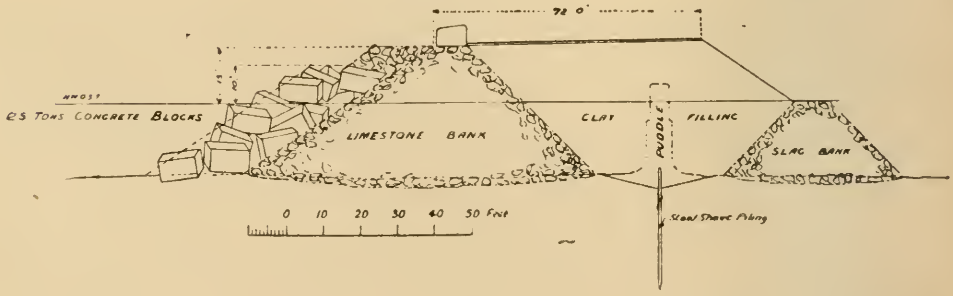
This accident had the effect of hastening the negotiations for the erection of an outer barrier, Plate 157, the necessity for which had already become apparent through the discovery of the fact that the ore body extended a long way seaward of the existing sea wall. In view of previous experience, Mr. Matthews, in designing this new and larger structure, which, like its predecessor, had to be both water-tight and sea proof, provided for a flexible bank instead of a rigid wall, so as to provide for such contingencies as connection between the outer foreshore and the mine hereafter, should such again occur.

The following description of this work has been written by Mr. H. Shelford Bidwell:—It will be seen, Fig. 3, that the outer barrier

— Fig. 3 —

— HODBARROW MINES — Cross Section of Outer Barrier

(In course of construction)



consists of a bank of rubble lime-stone, protected on the seaward side for the greater portion of its length by an outer covering of 25-ton concrete blocks deposited pell-mell, an inner and smaller bank of slag, with a filling of clay between these two banks. Where concrete blocks are not used the bank is protected by large lumps of limestone weighing from 8 to 15 tons. Under the centre of the clay bank, in order to form a cut-off, preventing percolation of water beneath the barrier, tongued and grooved sheet piling is driven into the bottom, this being of pitch-pine varying in length from 18 to 27 feet, or of steel 32 to 35 feet long, according to the nature of the foundation. Where the natural clay is near the surface the piling is dispensed with, and a puddle trench is substituted, the puddle being well keyed into the natural clay.

Over the piling or the puddle trench, as the case may be, a puddle wall is constructed in the heart of the clay bank, to prevent percolation of water through the barrier, being brought up to a level of 5 feet above high water of ordinary spring tides. The surface of the clay filling is to be covered with a layer of slag, and provision is made for a parapet of concrete blocks if found necessary.

There will be four sluice culverts through the barrier, constructed of concrete-in-mass, faced at the openings with granite masonry. The total length of the barrier is 6,870 feet, or rather more than a mile and a quarter. It has an extreme height of 40 feet, and its greatest width at the base is 210 feet. The area reclaimed by this barrier will be 170 acres. The contract for the work has been entrusted to Messrs. John Aird and Co., of Westminster, who, as already stated, were the contractors for the first sea wall.

In conclusion, it will be observed that both the sea wall and the new outer barrier are engineering works of a special and exceptional character, inasmuch as they combine the characteristics of a water-tight dam with those of a barrier possessing adequate strength to resist sea action.

LINDAL MINES, NEAR ULVERSTON.

The hematite ore mines of Messrs. Harrison, Ainslie and Co., situated at Lindal between Ulverston and Dalton, Plate 157, are the oldest in the district, having been worked for over 100 years by the present Company. They cover an area of several thousand acres, over which is spread a number of shafts of various depths and sizes, the principal ones being at Lindal Moor, Lowfield, and Berkune. Owing to the large quantity of water to be raised, a powerful pumping plant is necessary. The older engines are of the Cornish type, but the two recently erected by Messrs. Hathorn, Davey and Co., of Leeds, at Lowfield and Berkune are Davey's differential engines, the larger of which is at Lowfield. The shaft is inclined at an angle of 42°. The low-pressure cylinder is 80 inches in diameter and the high-pressure cylinder 45 inches; and both are steam-jacketed. The total length of the inclined shaft is about 1,150 feet, the vertical depth from the pump to the point of delivery is 735 feet, and the amount of water to be raised is 2,000 gallons per minute. The main pump, which is of the single-acting plunger type, is directly attached to the engine by means of a bell crank and spear rods. With the object of partially equalising the delivery on the indoor and outdoor strokes, a subsidiary ram 17 inches diameter is provided. This ram, which is hollow, is stationary, being connected to a branch on the delivery main, while the ram case is attached to and moves up and down with the spear rods, with the result that an amount of water equal to the displacement of this ram is subtracted from the delivery during the down stroke of the main plunger and re-delivered during the alternate up-stroke, the joint action being similar to that of an ordinary compound ram. The bell crank is balanced so as to equalise the work to be done on the outdoor and indoor strokes. The spear rod, 1,150 feet long, is 22 inches square, and is made up of lengths of four 11-inch rods jointed with steel spear-plates in the usual manner, and is carried on cast-iron rollers. The main plunger is 30½ inches in diameter, and has a stroke of 10 feet. The pump valves are double beat, and a duplicate set of valve boxes has been provided, controlled by a system of sluice valves, so that in the event of the failure of any valve the alternate set of valve boxes can at once be put into use.

GRAIN ELEVATOR, WYRE DOCK, FLEETWOOD.

This grain elevator belonging to the Lancashire and Yorkshire Railway Company is erected on the American principle. The building and all its arrangements were constructed, after mature consideration, from the plans of the English engineers specially sent over to America by the Railway Company, with the object of combining the best features of the practice in both countries, in dealing with the storage and delivery of grain. The elevator has a storage capacity of 150,000 quarters, in silos each of 1,000 quarters capacity.

The grain is taken from the vessel by means of a ship's leg elevator, 40 feet in length, which has buckets 18 inches long, running at 600 feet per minute, and discharging on to a conveying band 23 inches wide, running at 700 feet per minute, in a tunnel from the tower to the warehouse. In the basement of the warehouse there are two conveying bands running the whole length of the building, which carry the grain to any of the four elevators. These elevators are 6 feet 6 inches by 2 feet 4 inches inside, with buckets 20 inches long, 12 inches apart, and run at 600 feet per minute. They carry the grain to the top of the building and deliver it into receiving hoppers (two to each elevator), each of 10 tons capacity. It then falls into the weigh bins, each 8 feet diameter, and of 5 tons capacity, which feed the grain into Pooley's automatic weighing-machines. From the weighing-machines the grain is fed into distributing tubes which are so arranged that they can be placed over any silo. When the grain is required for delivery it is transferred to delivery silos, fitted with patent appliances for equalising the sample, and from thence is run into sacks for weighing by ordinary scale-beam machines, being placed thence into railway wagons which run on three sets of rails under the silos. These rails being connected to adjacent sidings lead directly to the main line.

On the left-hand side of the warehouse is the engine and boiler house. Steam is supplied by two Lancashire boilers 7 feet diameter by 29 feet length, working at a pressure of 70 lbs. per square inch. The machinery in the warehouse is driven by a pair of horizontal condensing engines fitted with Corliss gear, having cylinders 26 inches diameter by 48 inches stroke, and driving a fly rope pulley 20 feet diameter, having fourteen ropes of 1½ inches diameter running at 60 revolutions per minute. The warehouse is well protected against fire, having a pair of fire pumps with 8½-inch rams and cylinders 14 inches diameter by 16 inches stroke, besides numerous other appliances. The building is lighted throughout by electric light, there being two dynamos, each of 33-kilowatt capacity, driven by two vertical engines having cylinders 17 inches diameter by 16 inches stroke. Electric communication is established between the engine house and various parts of the warehouse. The elevator is fitted up with shakers, blowers, and all the latest improvements required to restore the condition of heated or damaged cargoes. It has frequently been filled to its utmost capacity, and the arrangements have at all times given every satisfaction, both in despatch to ships and facility for delivery.

The elevator machinery is on such a scale that the following operations can be performed at one and the same time:—

1. Discharging from vessels in the dock at a rate not surpassed in practice by any other agency of the kind.

2. Conveying from the quay to the weigh tower and distributing into any of the silos.

3. Weighing by hoppers in the towers at the top of the building.

4. Turning grain from silo to silo, or to delivery silo, and weighing through hopper when required.

5. Sacking grain, weighing, and loading into railway wagons and carts simultaneously.

6. Conveying from the elevator into barges or coasters.

On the opposite side of the dock are extensive grain sheds, capable of holding 80,000 quarters, in which grain not suitable for storage in the elevator silos can be stored on well seasoned and well drained floors in layers of 5 feet or upwards as required. Grain is conveyed from the ship into these sheds by means of steam cranes. No cartage or haulage is incurred from either the elevator or the sheds, delivery in all cases being made direct from and to the ship, by railway truck or cart as required.

The dock is 1,000 feet in length by 400 feet width, and the lock 250 feet by 50 feet. On the dock quay are eight 3- and 4-ton steam cranes, two 30-cwt. hydraulic travelling-cranes, and one 25-ton hydraulic coaling-crane, capable of tipping 250 tons per hour. This crane has given complete satisfaction, as it lowers and tips the wagons on deck level, thus ensuring a minimum breakage of coal. At the farther end of the dock is the timber pond, having an area of 15 acres and has never less than 4 feet of water. The logs are lifted by two 3-ton steam cranes; the timber is stored around the timber pond and behind the grain sheds, adjacent to the sidings leading to the main line.

CORPORATION ELECTRICITY WORKS, BLACKPOOL.

This Electricity Station, situated in West Caroline Street, was opened in 1893. Its capacity is 3,100 kilowatts, including that of the traction plant. There are now being installed two sets of 250 and one set of 500-kilowatt Parsons turbine engine. Steam is generated in five Lancashire boilers, two Fraser's marine type, and five Babcock and Wilcox boilers fitted with chain grates and mechanical stokers, the working pressure being 120 lbs. per square inch. The system employed is high-tension alternating, and the pressure at the station is 2,000 volts, and at the consumers' terminal 200 volts on the two-wire system. High-tension twin cables of 0·1 inch diameter, laid on the ring system, radiate from the works to thirteen transformer chambers, and mains of 0·062 inch diameter interconnect these.

Street Lighting.—There are erected at present 260 arc lamps of various types, which are run on the series system with rectified current. There are also about 300 incandescent lamps of 8 candle-power fixed on arc and traction posts supplied off the 200-volt lighting main. The price is 7*d.* and 2*d.* per unit.

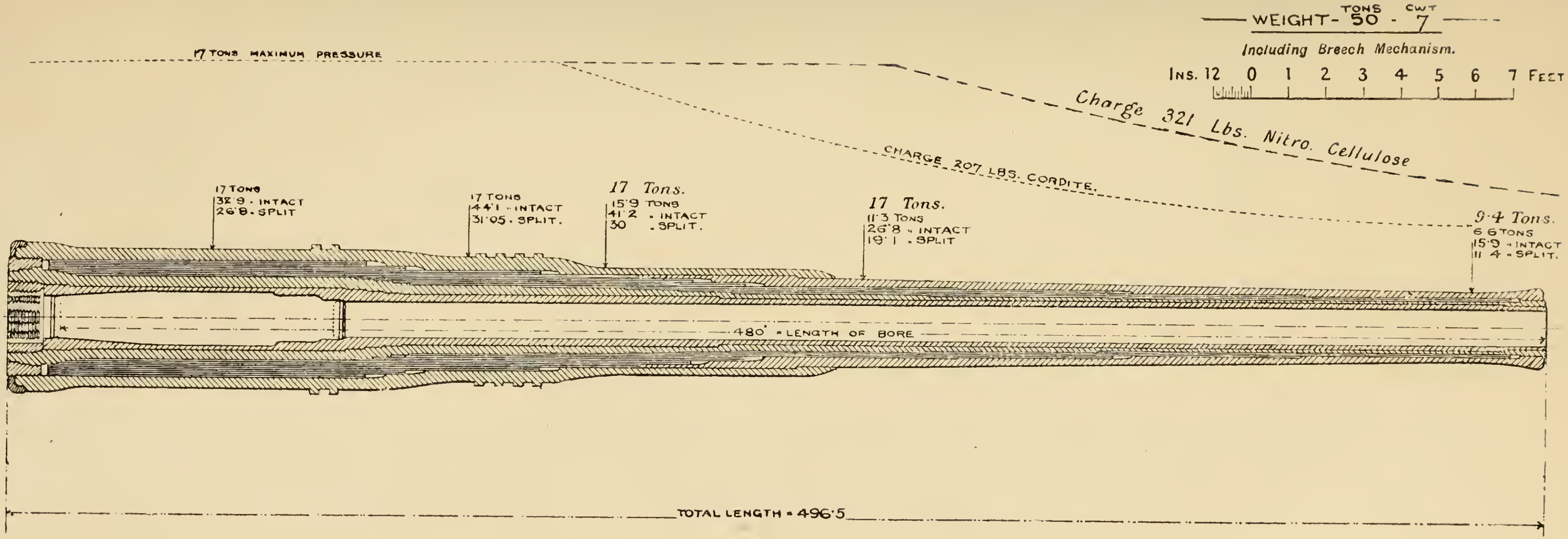
Tramways.—These have been in operation since 1885 on the conduit system, but the trolley system was adopted in June 1899, the pressure being 500 volts. About 14 miles of single track of 4 feet 8½ inches gauge have been laid. The rails are of the girder type, at 95 lbs. per yard. The trolley wire is 000 gauge, supported by bracket arm poles fixed on the side of the road. There are 41 cars of the double-decked type, 16 bogie and 25 single cars; the former seat 95 passengers and the latter 50. Each car is drawn by two 27-H.P. motors, which are operated by series parallel controllers. The line is fed by 0·3 inch and 0·2 inch single cable from section boxes fixed every half-mile. Mr. Robert C. Quin, M.I.Mech.E., is the Borough Electrical and Tramway Engineer.

THE BLACKPOOL AND FLEETWOOD TRAMROAD COMPANY'S POWER HOUSE, BISPHAM.

The Central Power Station and principal Car Shed and Shops are situated at Bispham, six miles from Fleetwood, two miles from Blackpool Terminus, and a quarter of a mile from the line. All the buildings, including the chimney, are of brick. For steam raising there are four Lancashire boilers, each 30 feet by 8 feet, the steam pressure is 120 lbs., hand fired, natural draught, the chimney being 180 feet high. The feed-water is obtained from a reservoir, adjacent to the engine room, which is filled by surface water, collected from the surrounding fields and springs; after passing through the hot-well the water is fed to the boilers through a Reeves filter and Green's economiser, by Worthington and Weir's direct steam-driven feed-pumps. In the engine room are five open marine type vertical compound engines of 200 H.P., with cylinders 12 inches by 24 inches in diameter, constructed by Messrs. Mather and Platt, direct coupled to five multipolar shunt-wound dynamos, each capable of giving a continuous output of 120 kilowatts at 505 volts. The engines are run condensing on two Ledward ejector condensers, coupled in parallel, the condensing water being cooled by the reservoir at light loads and by a Klein's cooler at heavy loads. The cooling tower is able to deal with 70,200 gallons of water per hour, taking down the temperature from 115° to 85° F. with the atmosphere at 70° F., the cooler having an efficiency of 75° F. The switchboard is fitted with the usual measuring instruments, switches and automatic circuit breakers of the "Cutler" type, and Board of Trade testing instruments. There are three boosters which stand along the side of the switchboard, two of which are used for boosting the batteries at Fleetwood and Bispham. The other is a negative booster taking the current back to the power house from the track so as to keep within the Board of Trade drop. All steam and exhaust pipes are placed in a basement beneath the engine room, giving easy access to all parts. The steam pipes are steel arranged in the form of a ring. The rolling stock consists of thirty motor-cars and three trailers, complete equipment by the British Thomson-Houston Company, and by Messrs. Dick, Kerr and Co. The General Manager is Mr. John Cameron, and the Electrical Engineer is Mr. Joseph McMahon.

NAVAL ORDNANCE.

Fig. 1. *12-inch, 40 Calibres B.L. Gun. (British type.)*



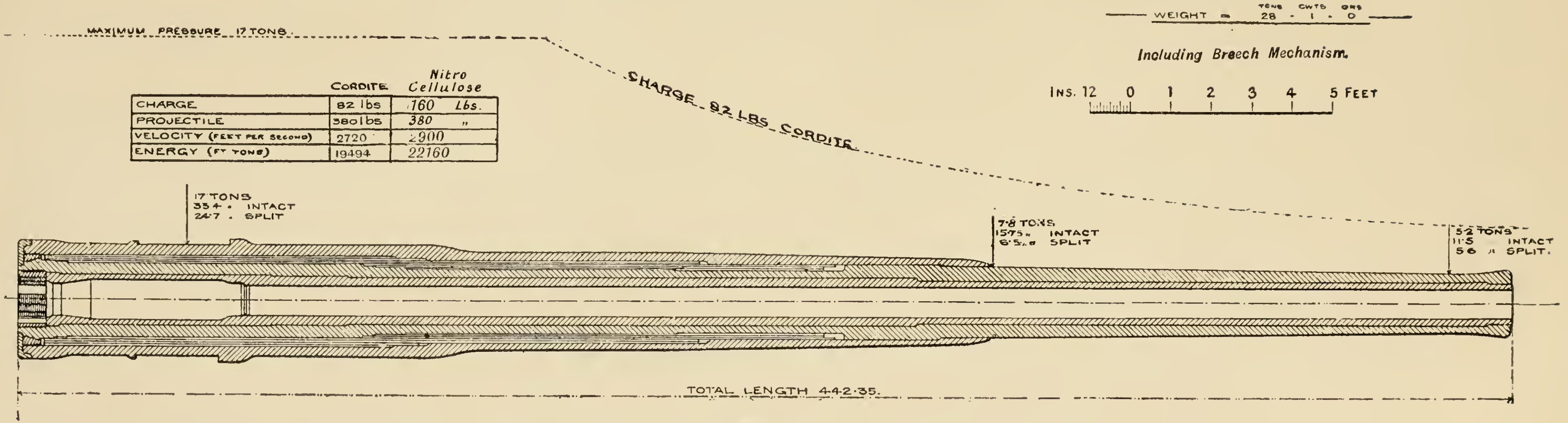
	CORDITE	Nitro Cellulose
CHARGE	207 LBS	321 lbs.
PROJECTILE	850 "	850 "
VELOCITY (FEET PER SECOND)	2516	2674
ENERGY (FOOT TONS)	37310	42144

Mechanical Engineers 1901.

NAVAL ORDNANCE.

Fig. 2.

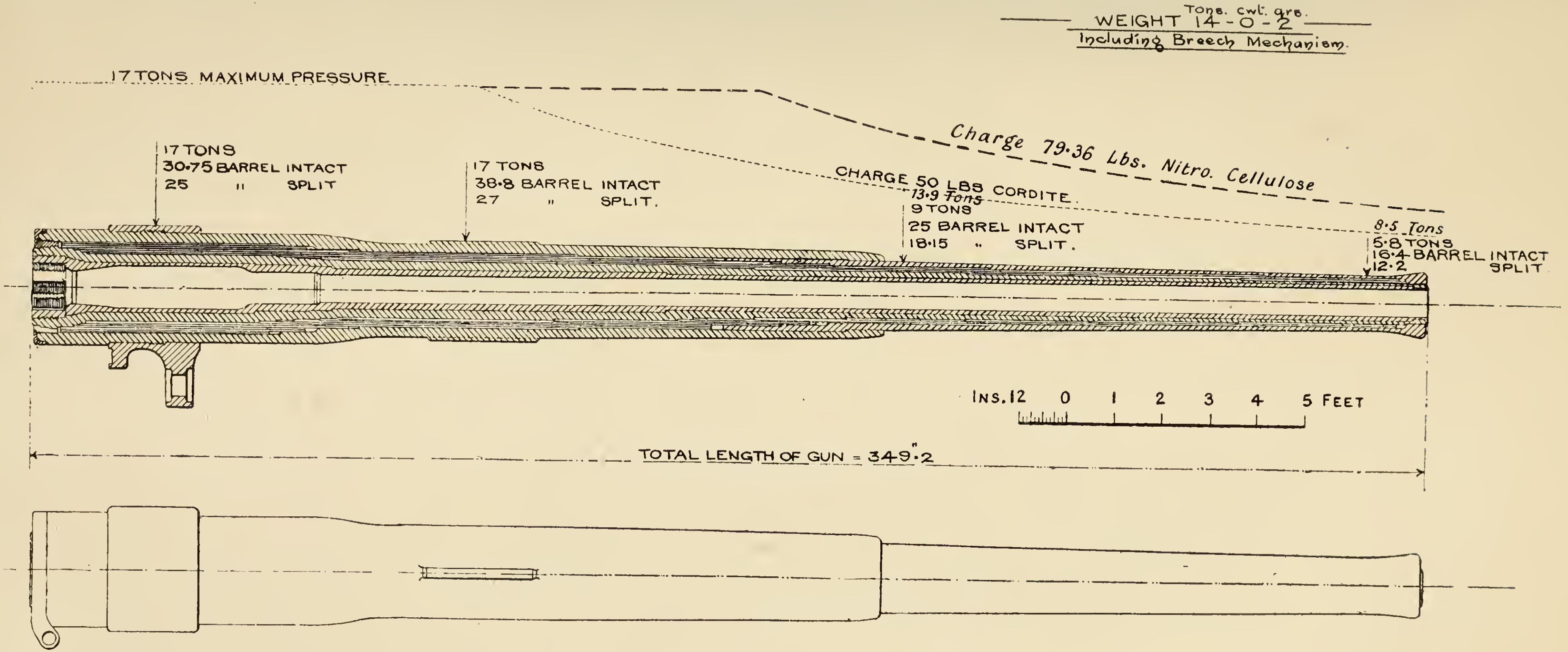
9·2-inch B.L. Gun. (Turkish type.)



	CORDITE	Nitro Cellulose
CHARGE	82 lbs	160 Lbs.
PROJECTILE	380 lbs	380 "
VELOCITY (FEET PER SECOND)	2720	2900
ENERGY (FT TONS)	19494	22160

NAVAL ORDNANCE.

Fig. 3. *Ordnance Q.F. 7·5-inch, 45 Calibres.* (*British type.*)

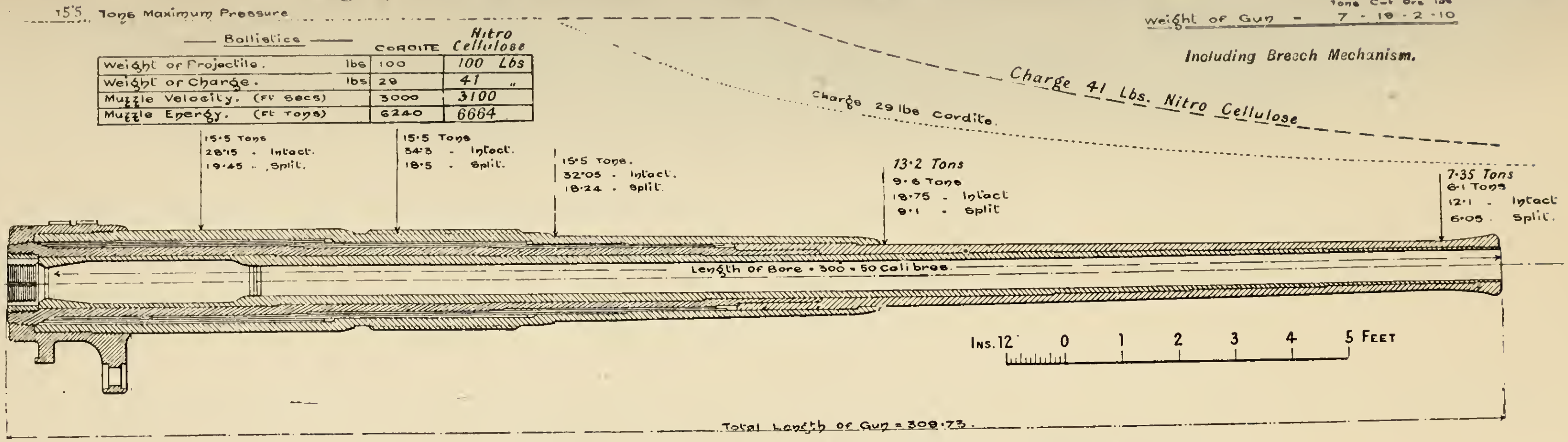


	CORDITE	Nitro Cellulose
CHARGE	50 LBS	79·36 Lbs.
PROJECTILE	200 "	200 "
VELOCITY (FEET PER SECOND)	2775	2920
ENERGY (FOOT TONS)	10680	11825

Mechanical Engineers 1901.

Plate 65.

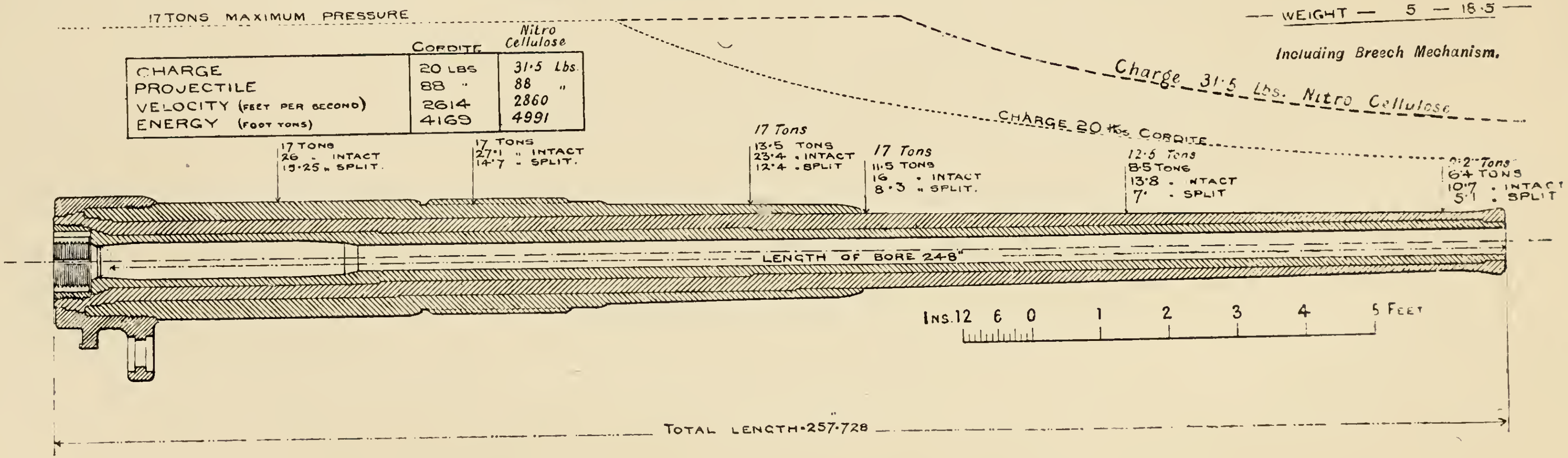
Fig. 4. *Ordnance Q.F. 6-inch Wire, 50 Calibres. (Japanese type.)*



— Ballistics —

		Cordite	Nitro Cellulose
Weight of Projectile.	lbs	100	100 Lbs
Weight of Charge.	lbs	29	41 "
Muzzle Velocity. (Ft Secs)		3000	3100
Muzzle Energy. (Ft Tons)		6240	6664

Fig. 5. *Ordnance Q.F. 14 c/m, 45 Calibres. (Spanish type.)*



	Cordite	Nitro Cellulose
CHARGE	20 LBS	31·5 Lbs.
PROJECTILE	88 "	88 "
VELOCITY (FEET PER SECOND)	2614	2860
ENERGY (FOOT TONS)	4169	4991

Plate 66.

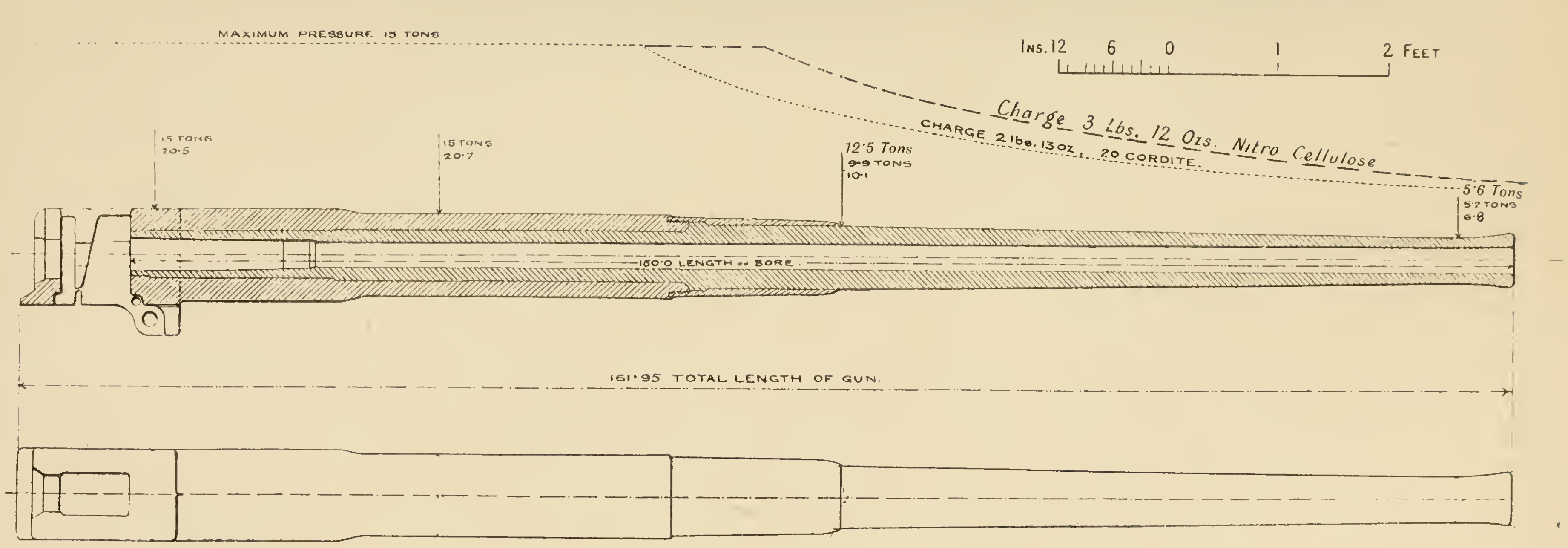
NAVAL ORDNANCE.

Fig. 6.

3-inch (14 Pdr.) Semi-Automatic Q.F. Gun. 50 Calibres. (U.S.A. type.)

WEIGHT OF GUN = 16 CWTS. 3 QRS. 17 LBS.

Including Breech Mechanism.



	CORDITE	*Nitro Cellulose*
CHARGE	2 lbs. 13 oz	3 Lbs. 12 oz.
PROJECTILE	14 lbs	14 "
VELOCITY (FEET PER SECOND)	2500	2630
ENERGY (FOOT TONS)	606 5	671

Mechanical Engineers 1901.

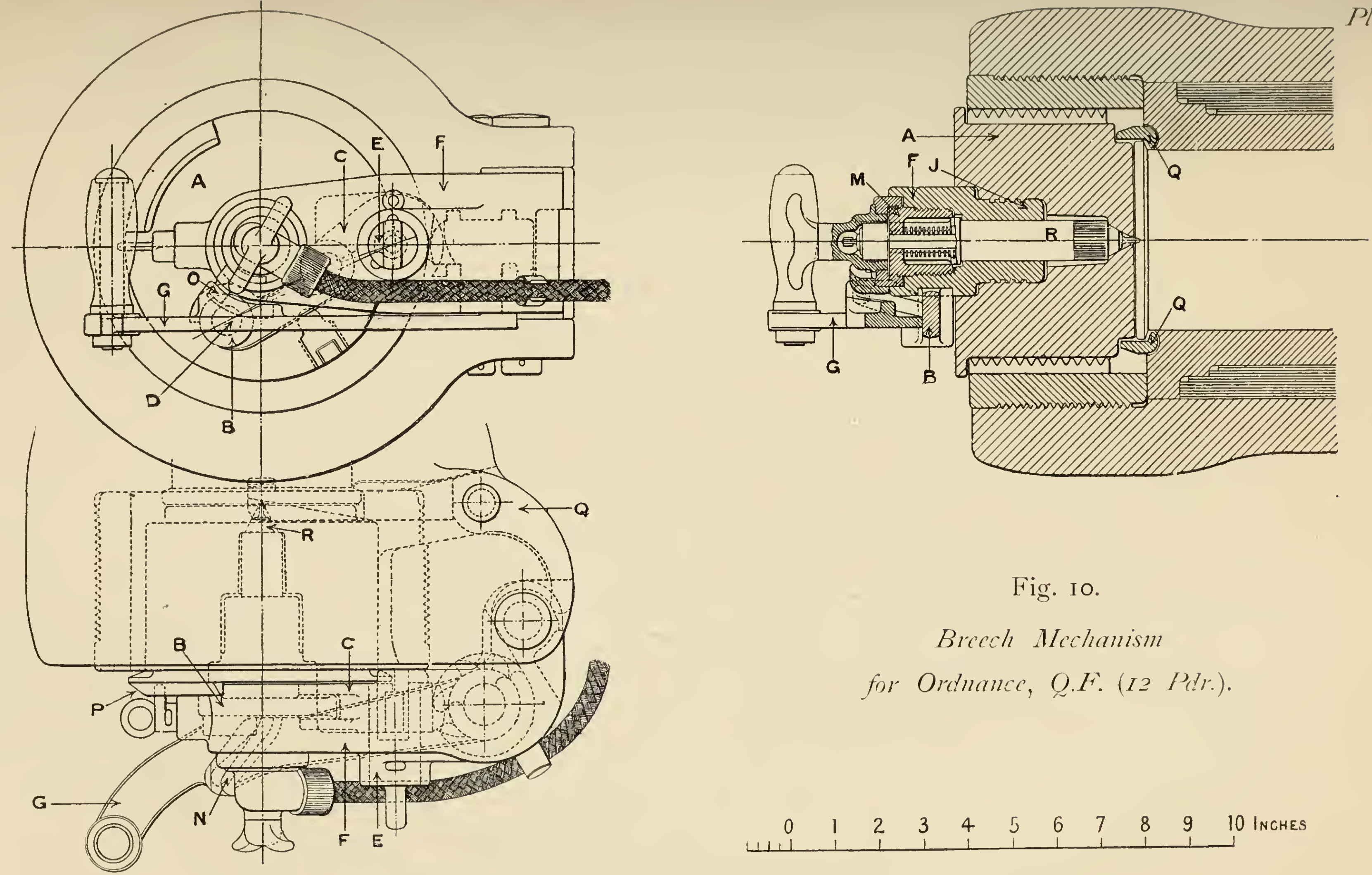


Fig. 10.

Breech Mechanism

for Ordnance, Q.F. (12 Pdr.).

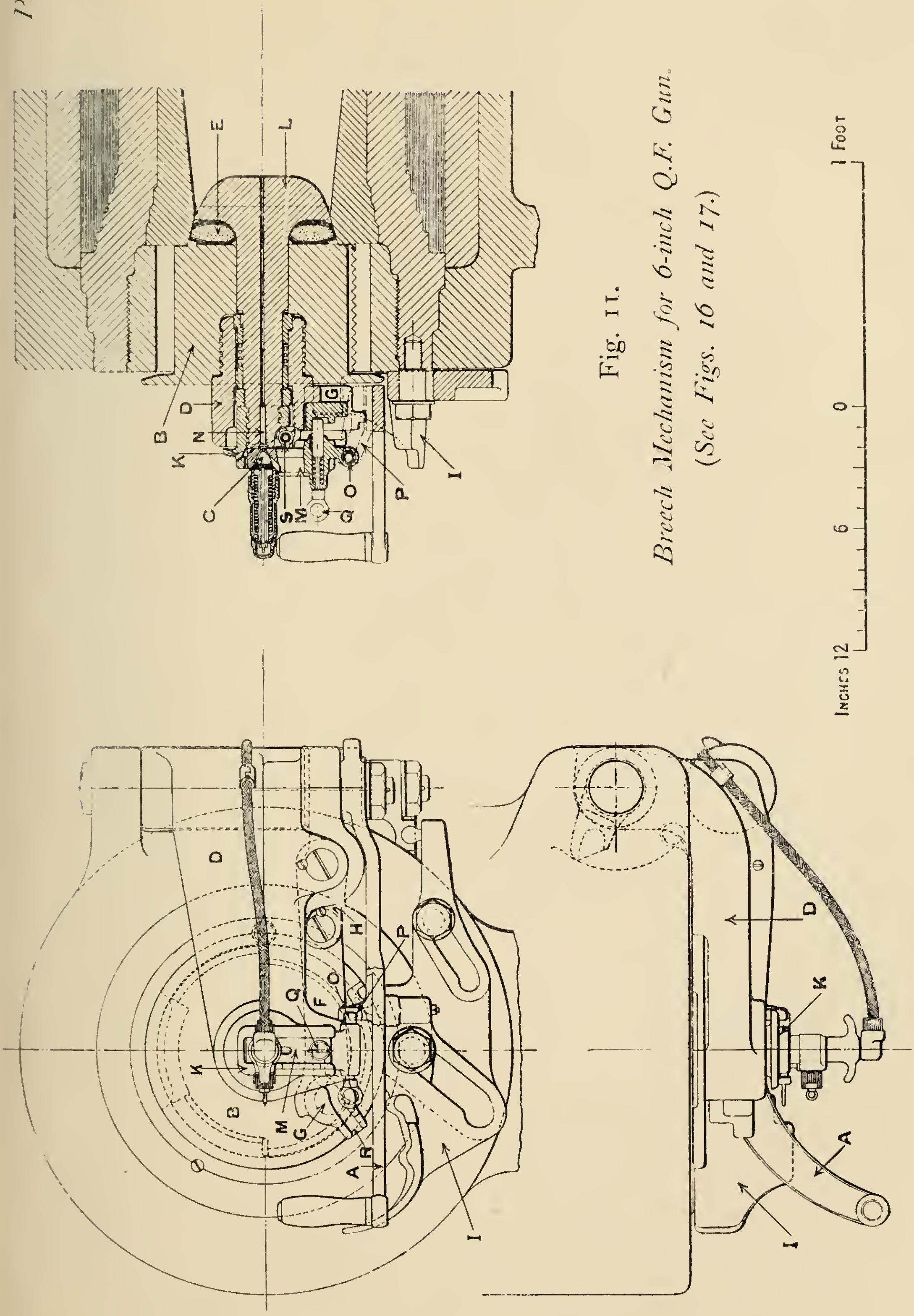


Fig. 11.

Breech Mechanism for 6-inch Q.F. Gun.

(See Figs. 16 and 17.)

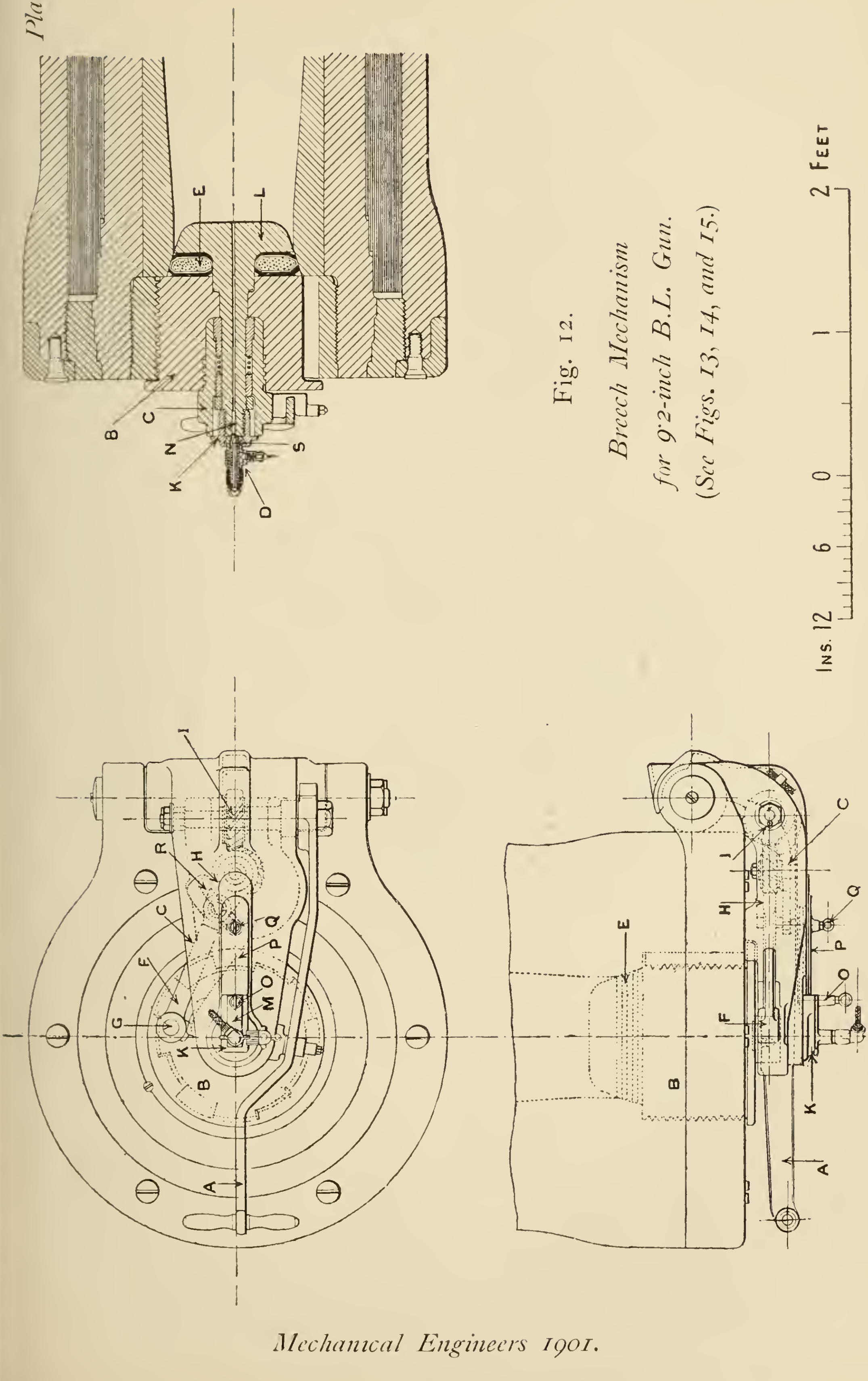


Fig. 12.

Breech Mechanism
for 9·2-inch B.L. Gun.
(See Figs. 13, 14, and 15.)

Breech Mechanism for 9·2-inch B.L. Gun. (See Fig. 12.)

Fig. 13.

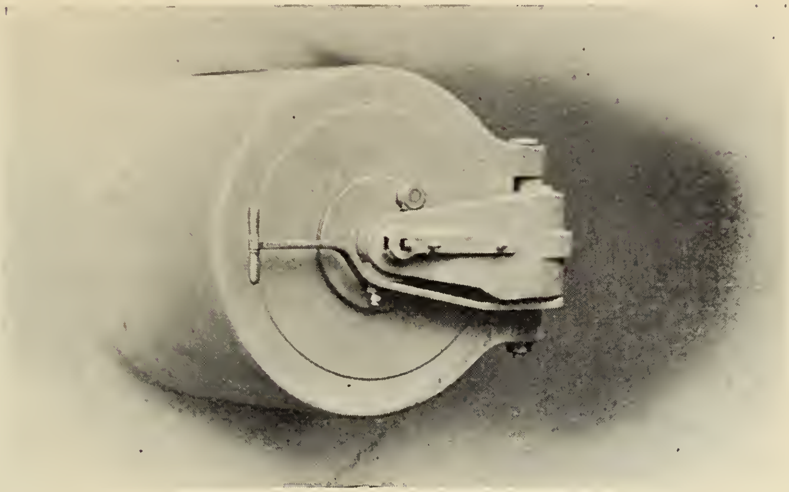


Fig. 14.

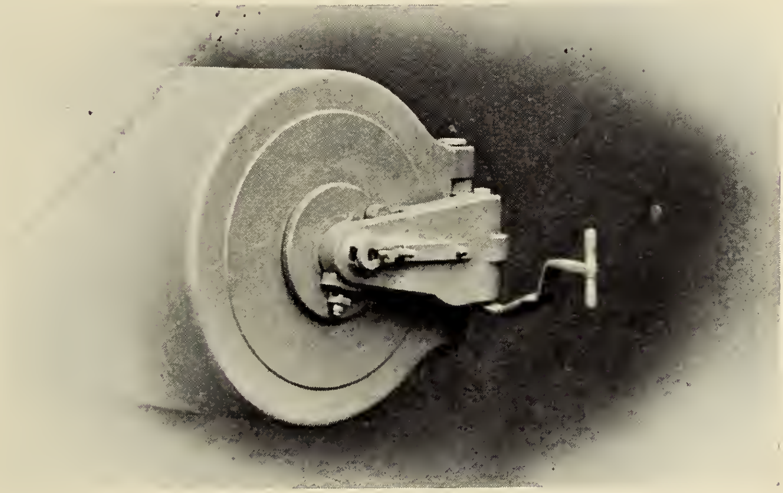


Fig. 15.

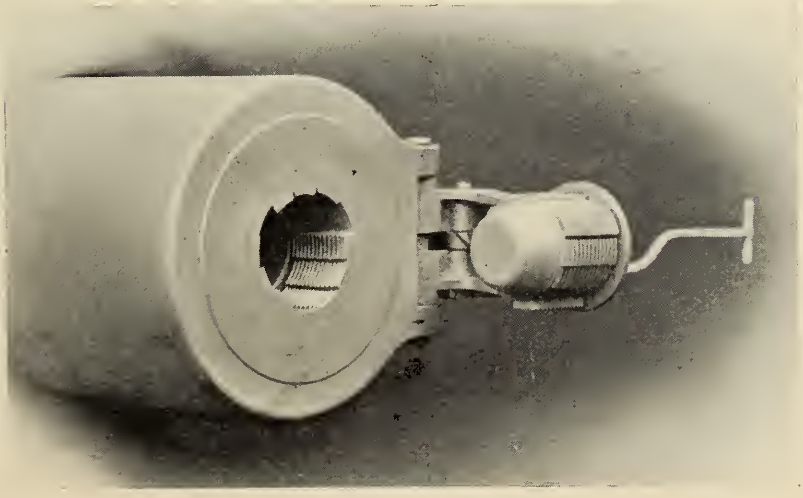


Fig. 16.

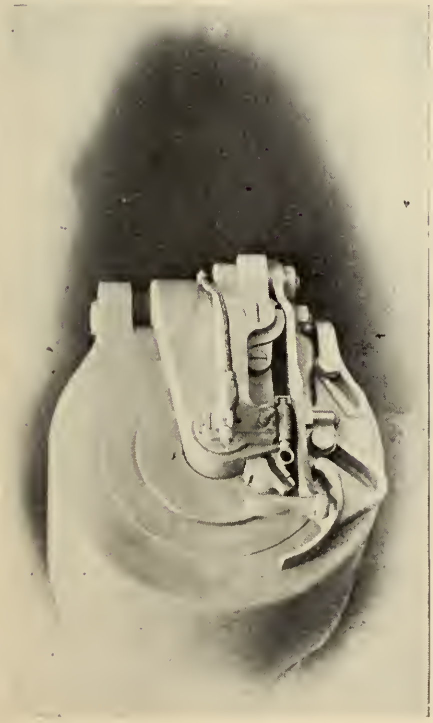
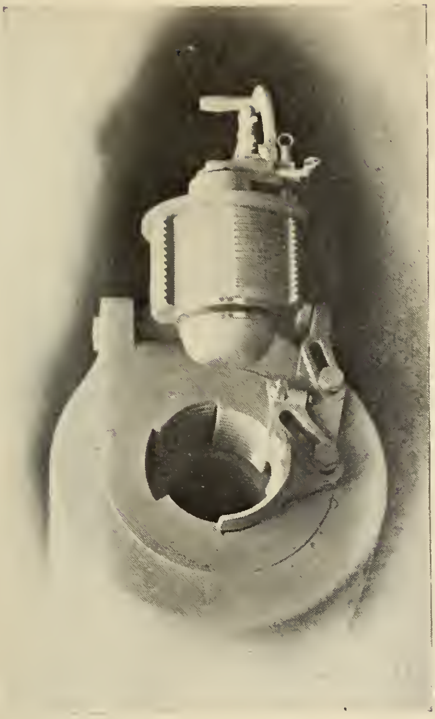


Fig. 17.



Breech Mechanism for 6-inch Q.F. Gun. (See Fig. 11.)

Fig. 18.

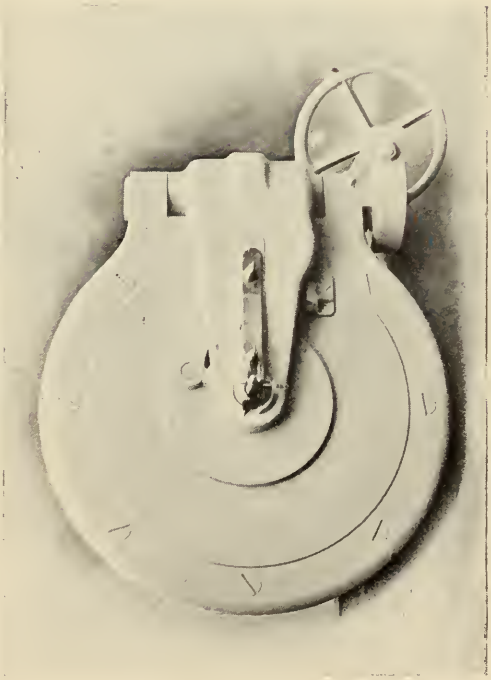
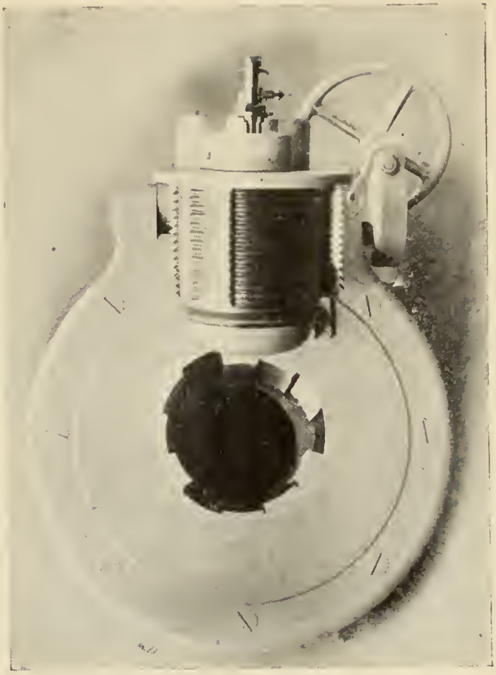


Fig. 19.



Breech Mechanism for 12-inch B.L. Gun. (See Fig. 20.)

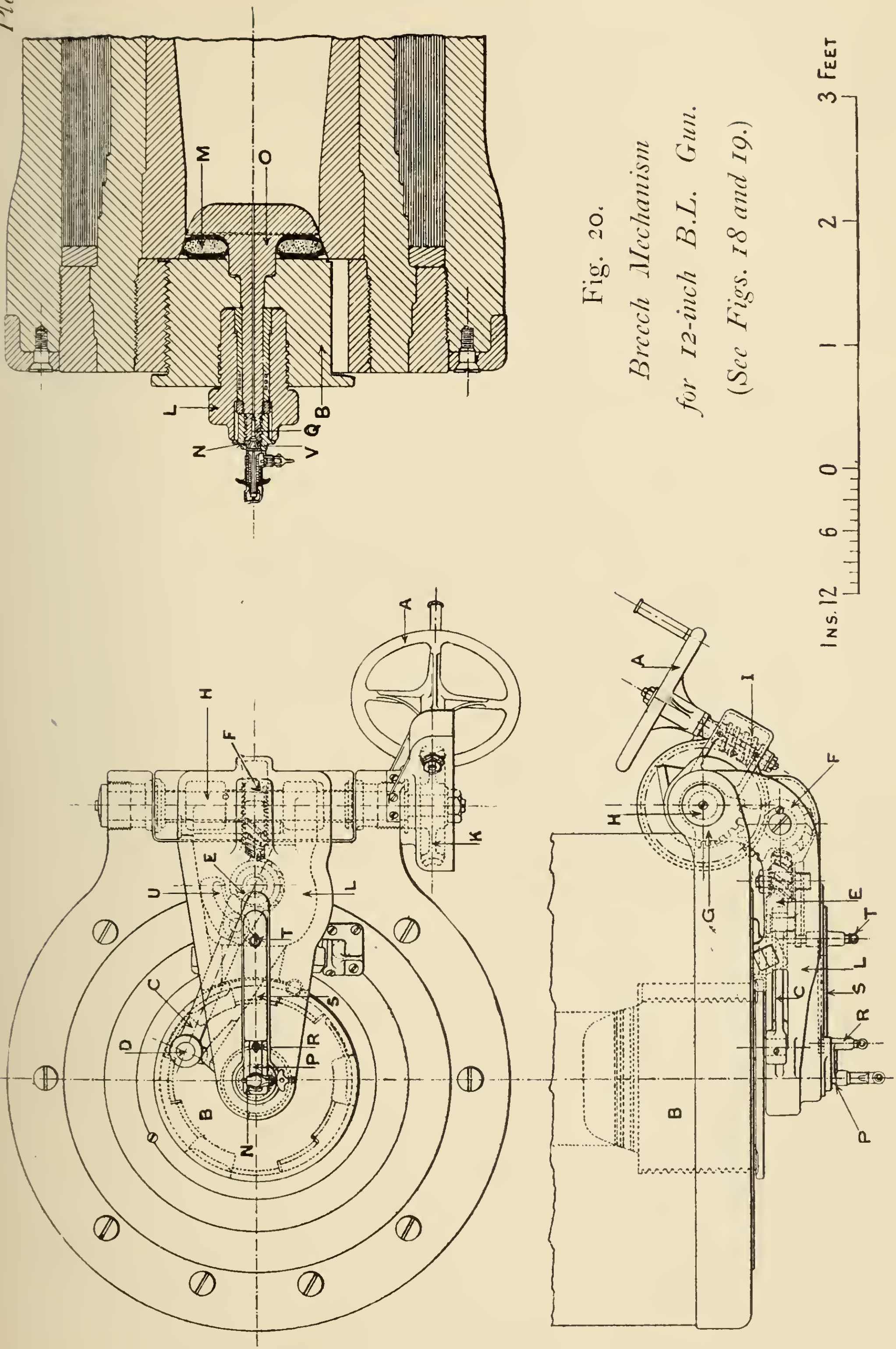


Fig. 20.

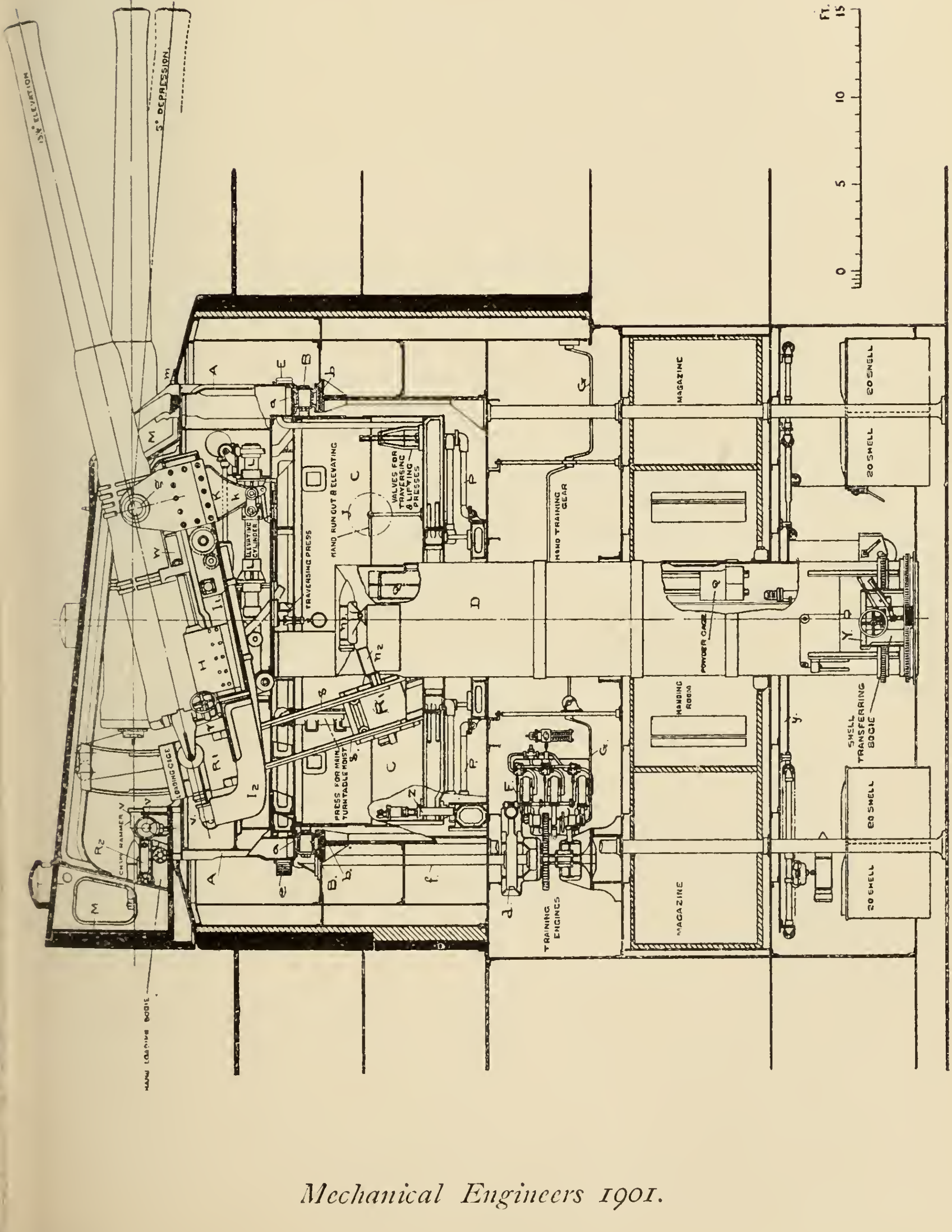
Breech Mechanism

for 12-inch B.L. Gun.

(See Figs. 18 and 19.)

Fig. 21.

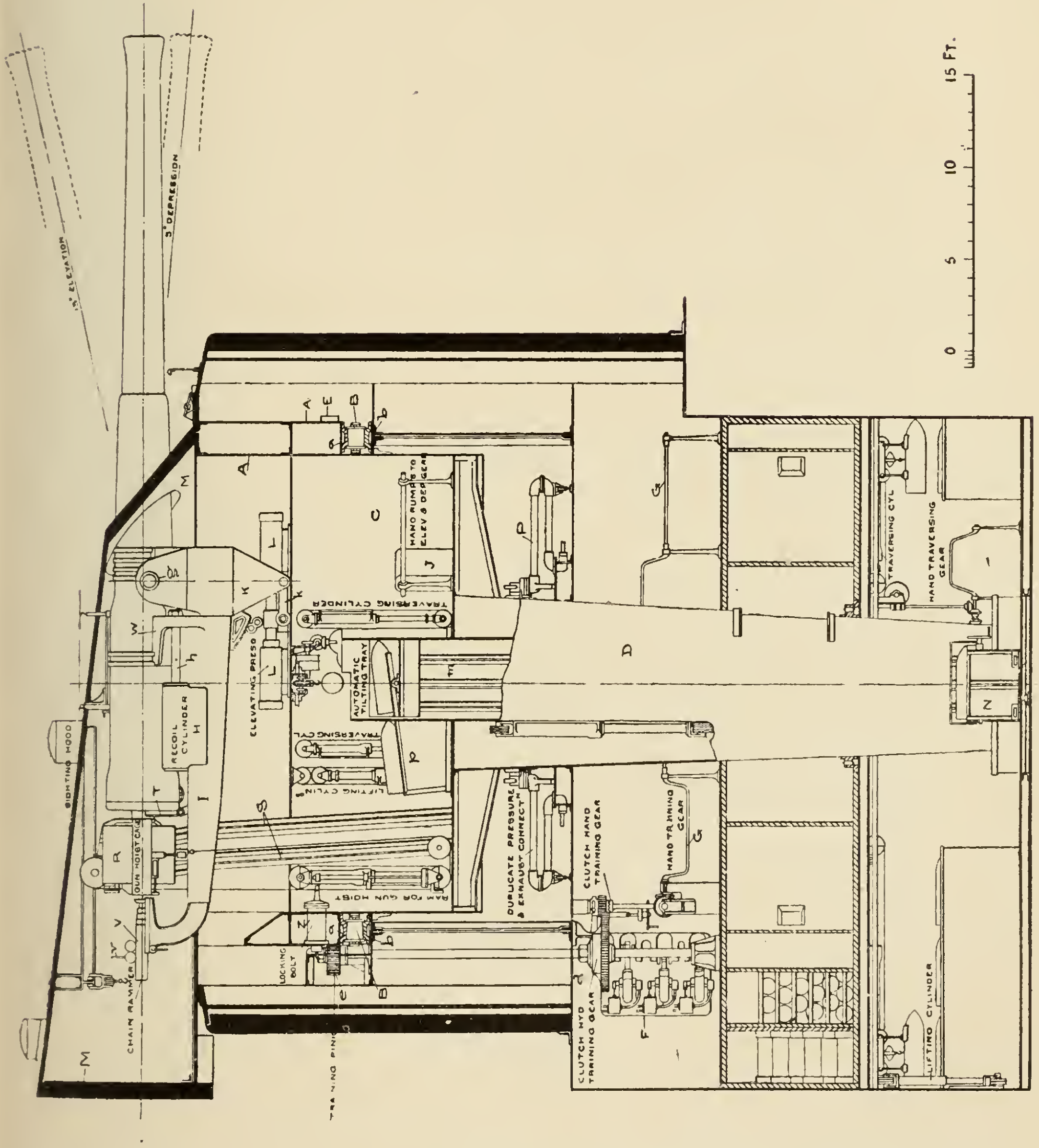
Barbette Mounting for two 12-inch B.L. Guns, as supplied to some British Battleships.



Mechanical Engineers 1901.

Fig. 22.

Barbette Mounting for two 12-inch B.L. Guns.



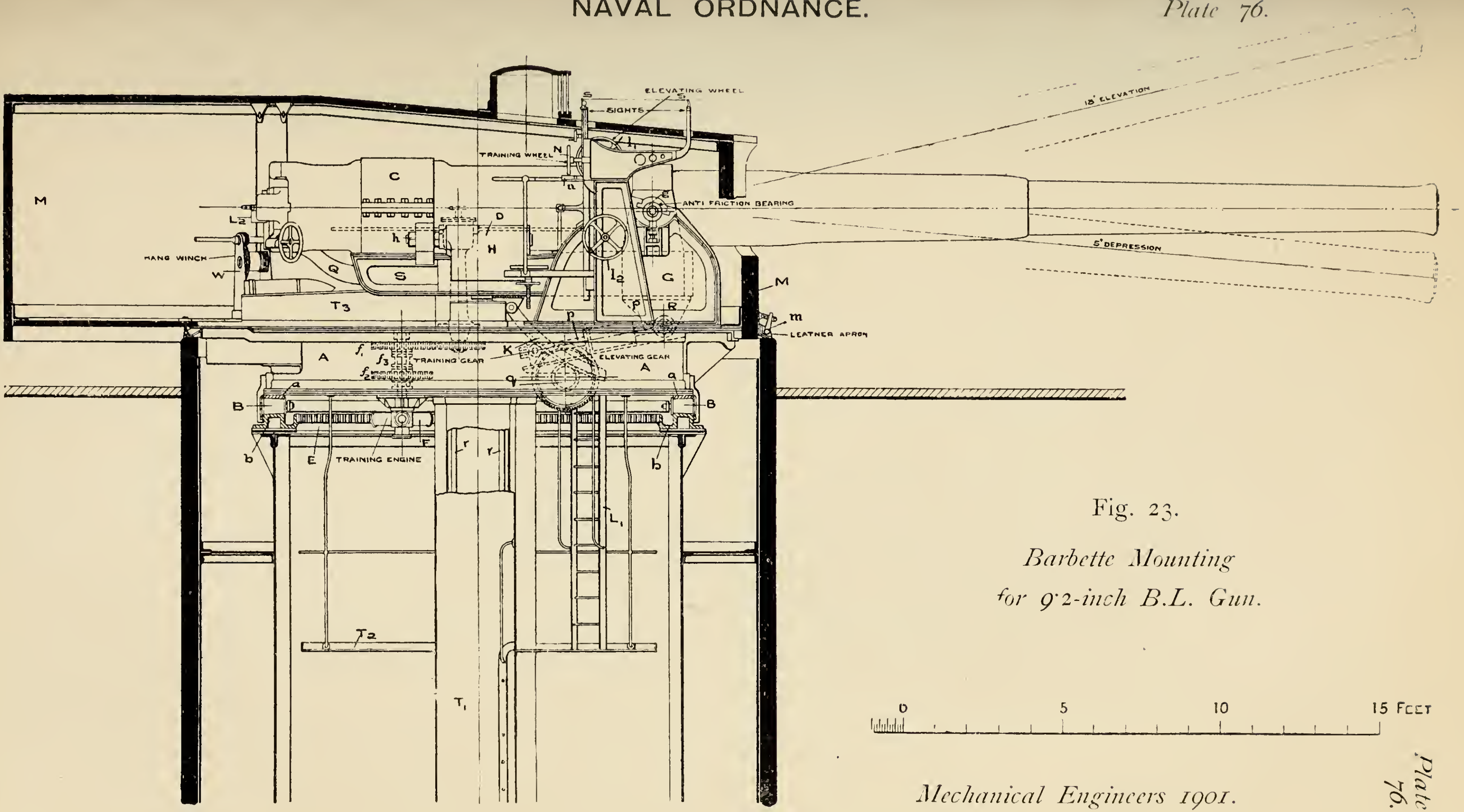
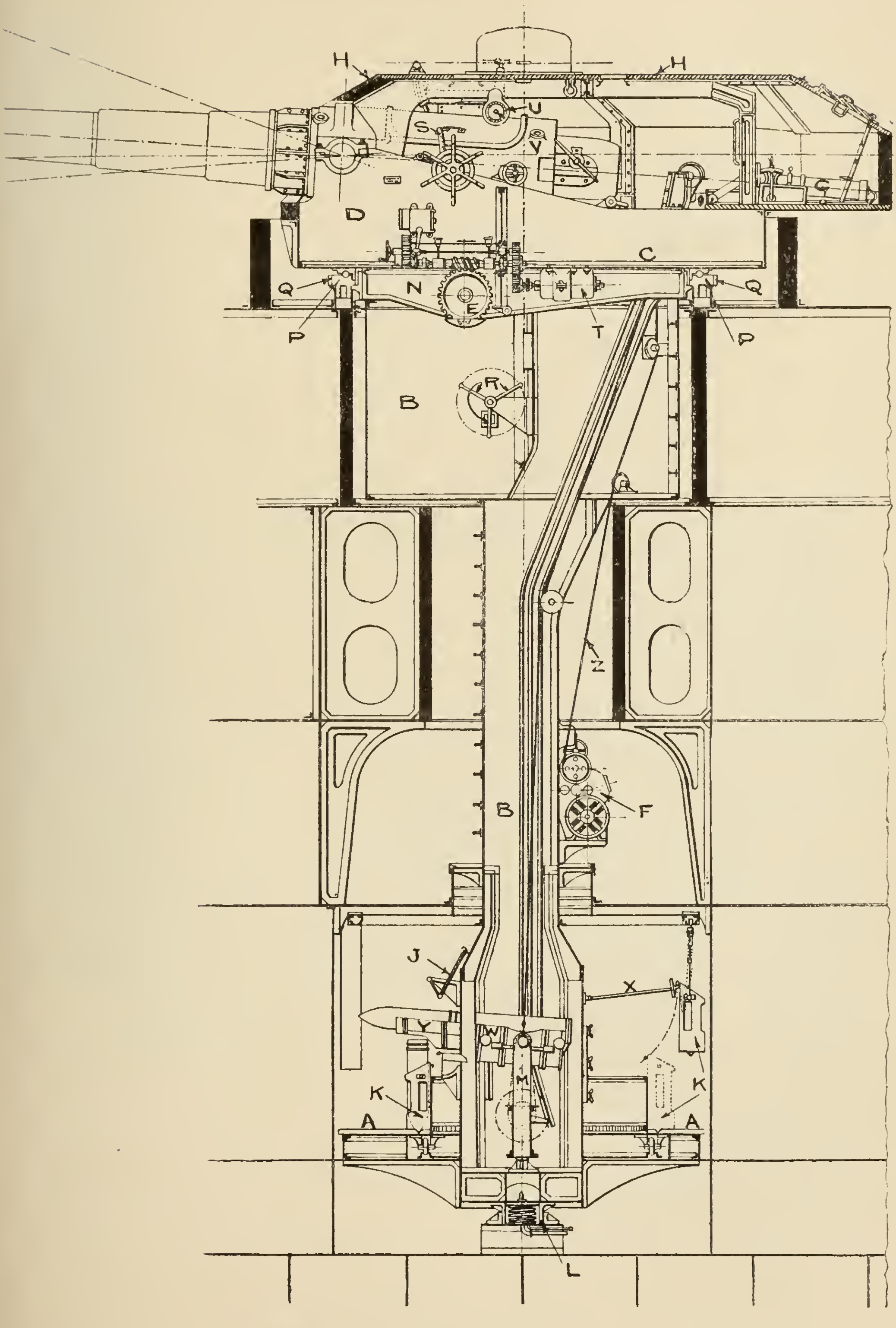


Fig. 23.

Barbette Mounting
for 9·2-inch B.L. Gun.

Fig. 24.

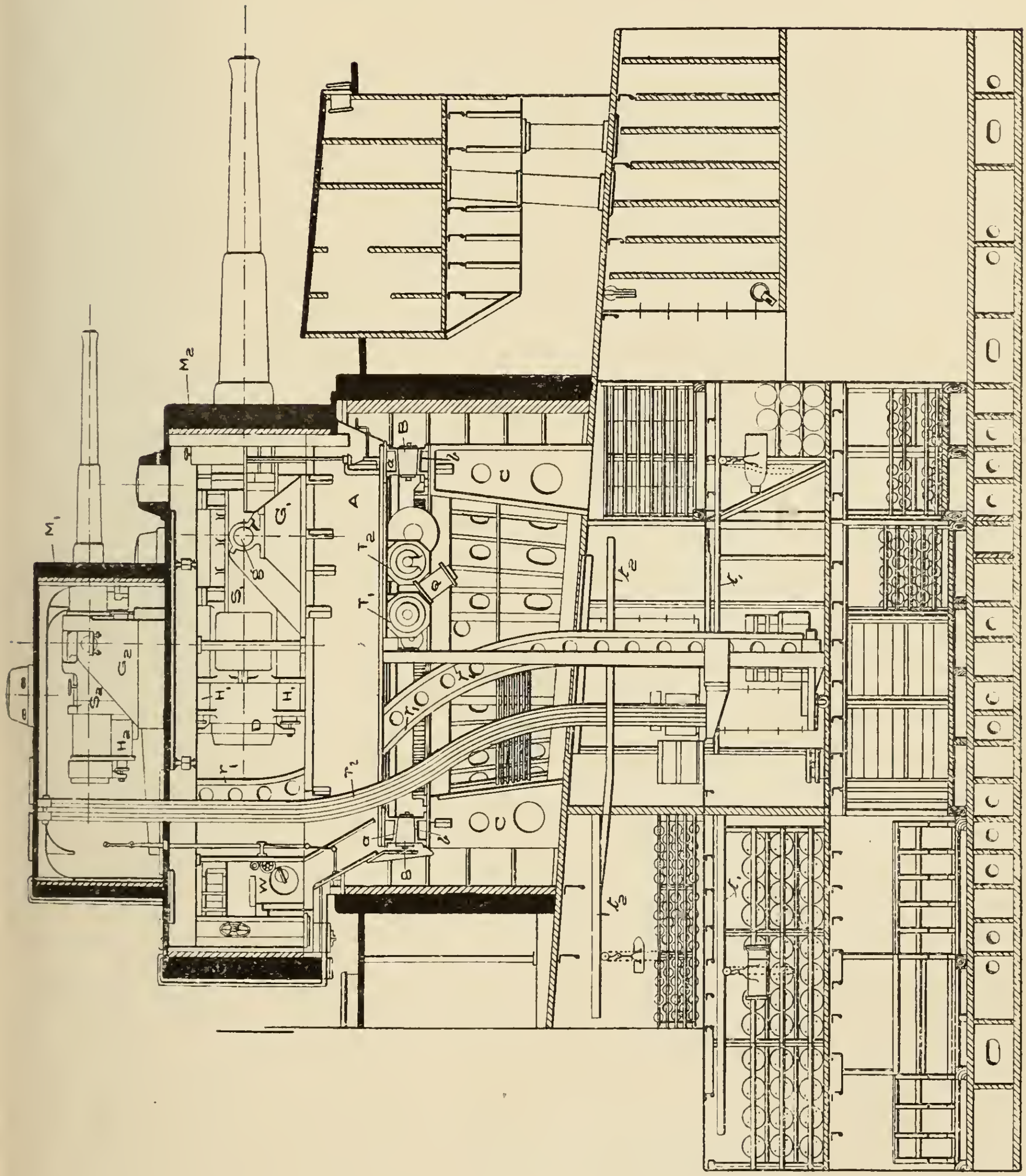
Barbette Mounting for 24 c/m B.L. Gun. (Krupp type.)



Mechanical Engineers 1901.

Fig. 25.

Barbette Mounting
for 13-inch and 8-inch Guns.
(U.S.A. type.)



NAVAL ORDNANCE.

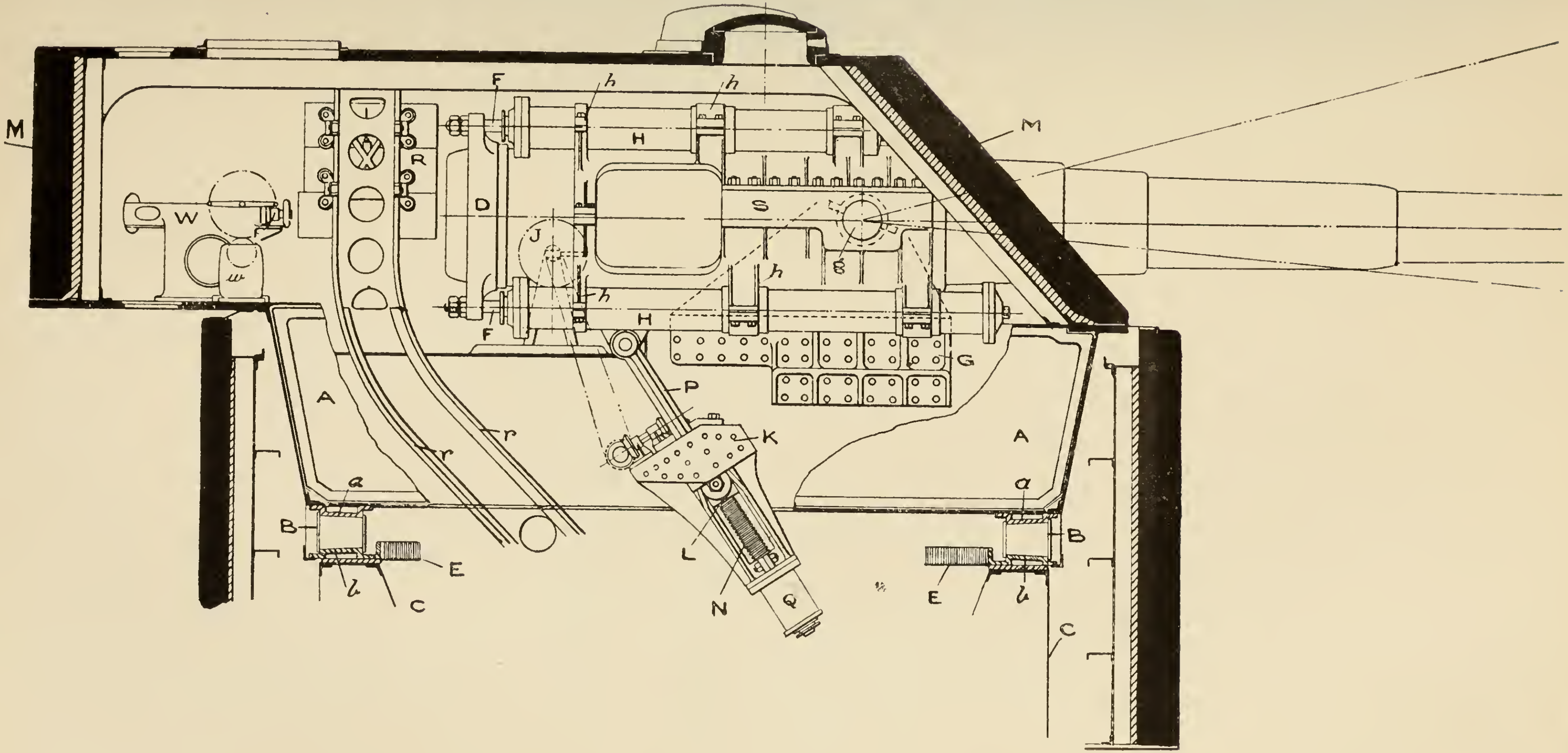


Fig. 26. *Barbette Mounting for two 13-inch Guns. (U.S.A. type.)*

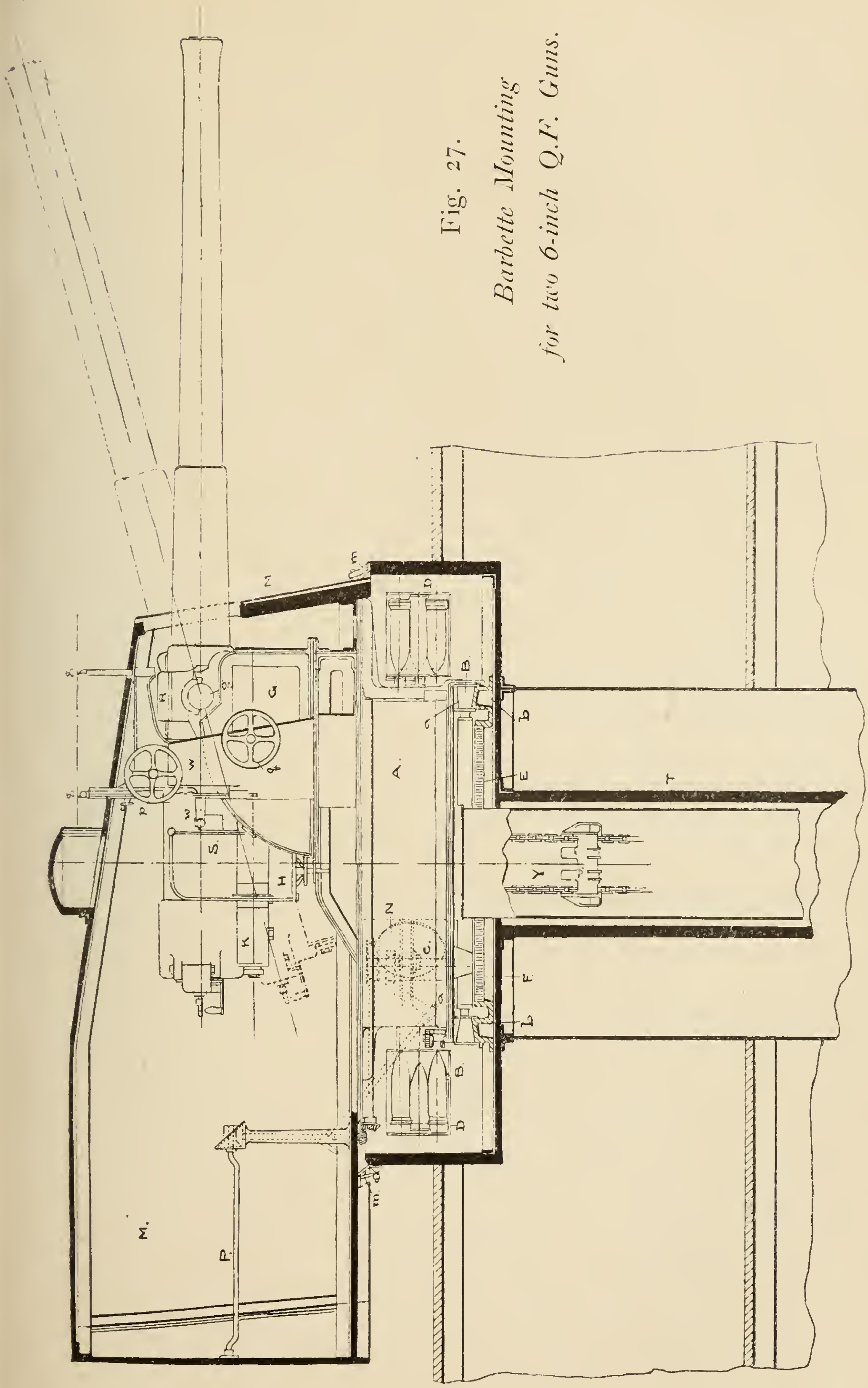
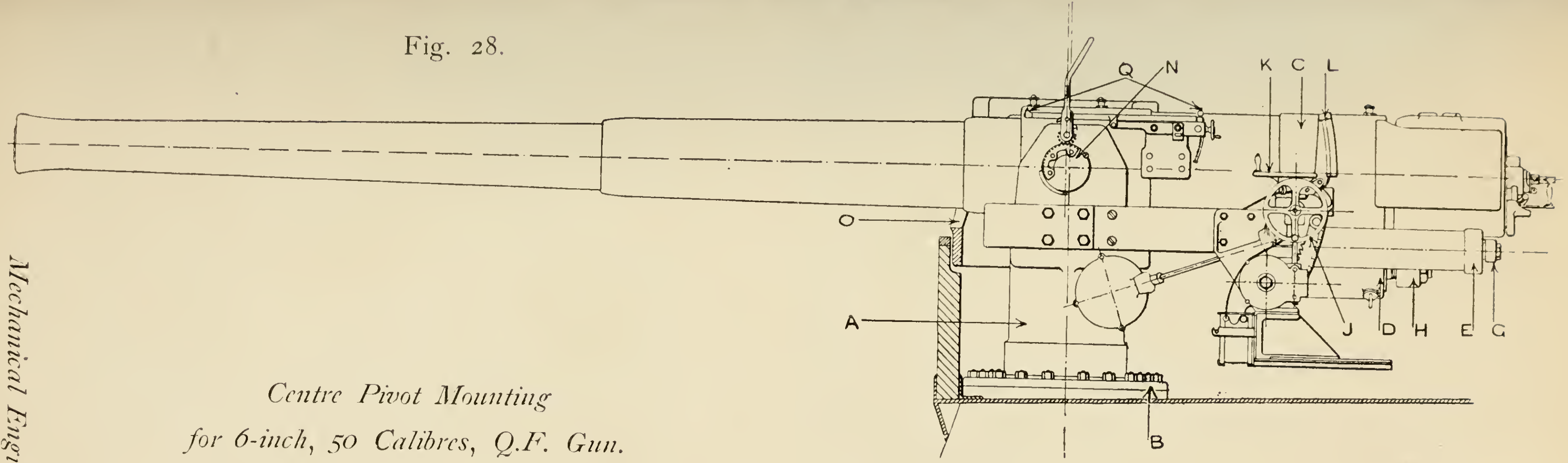


Fig. 27.

Barbette Mounting for two 6-inch Q.F. Guns.

Fig. 28.



Centre Pivot Mounting
for 6-inch, 50 Calibres, Q.F. Gun.

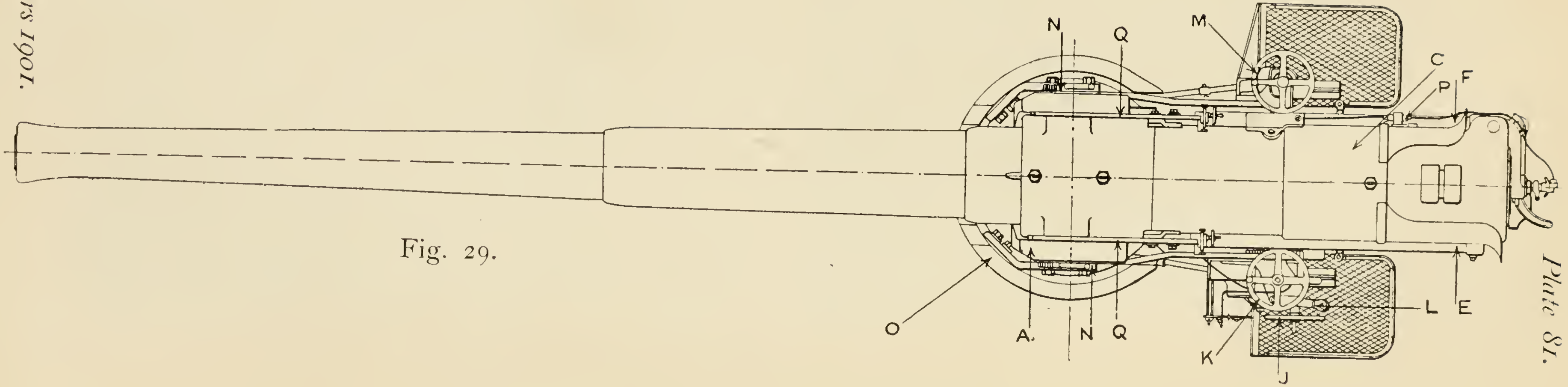


Fig. 29.

Fig. 30. *6-inch Q.F. Gun on Centre Pivot Mounting.*

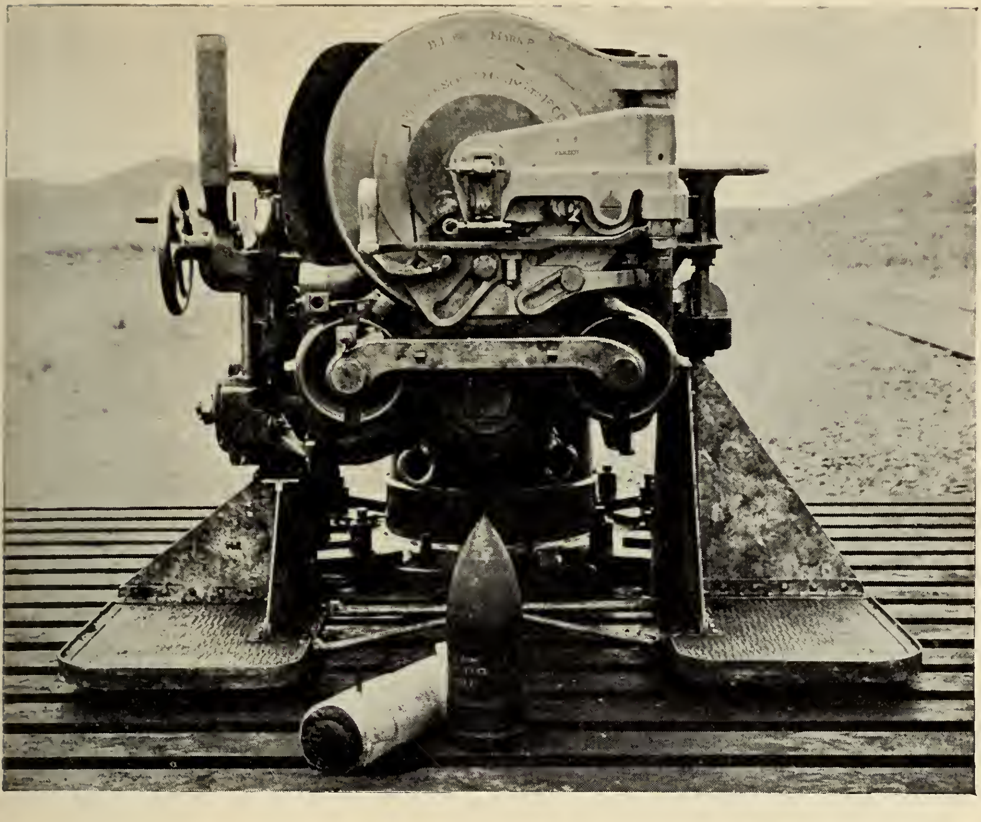


Fig. 31. *The same.*

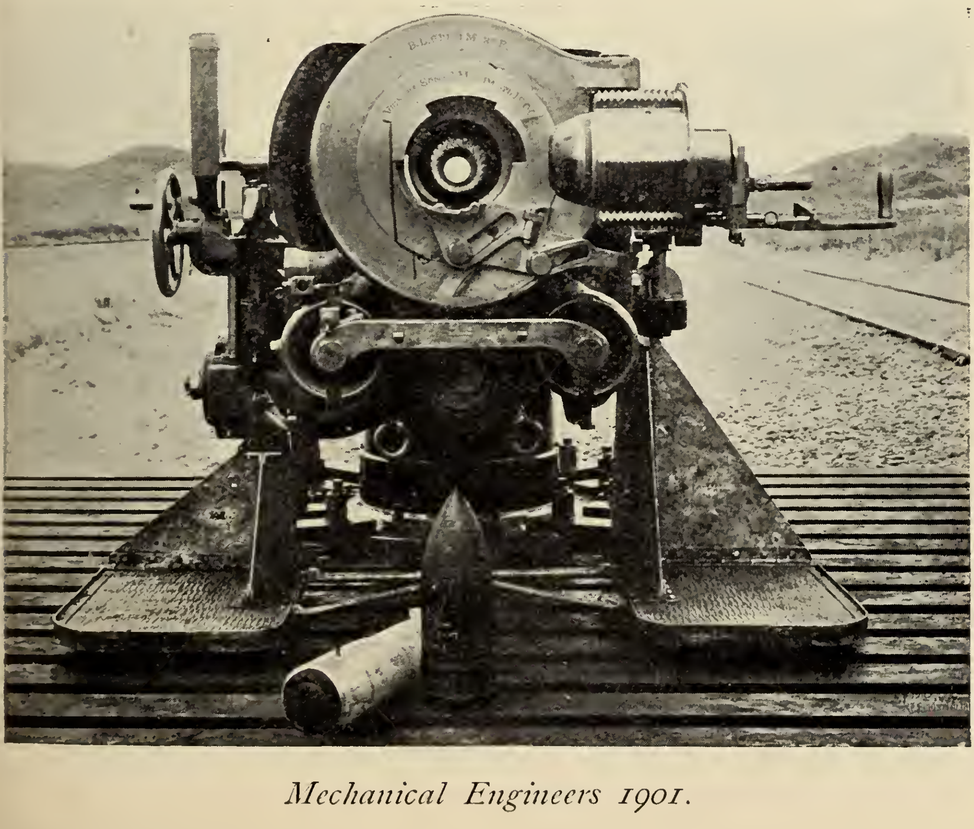


Plate 83.

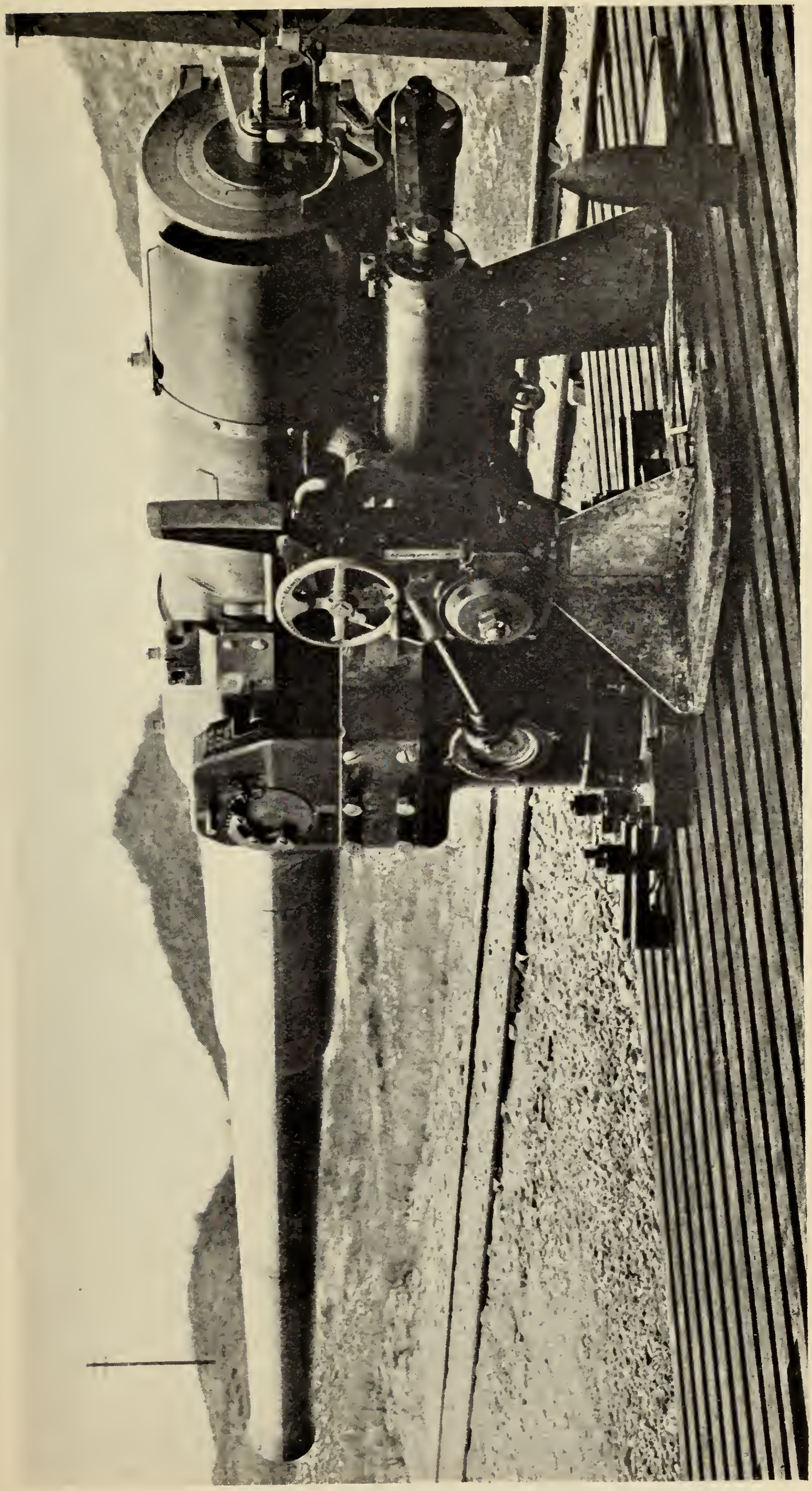


Fig. 32. *6-inch Q.F. Gun on Centre Pivot Mounting.*

Mechanical Engineers 1901.

NAVAL ORDNANCE.

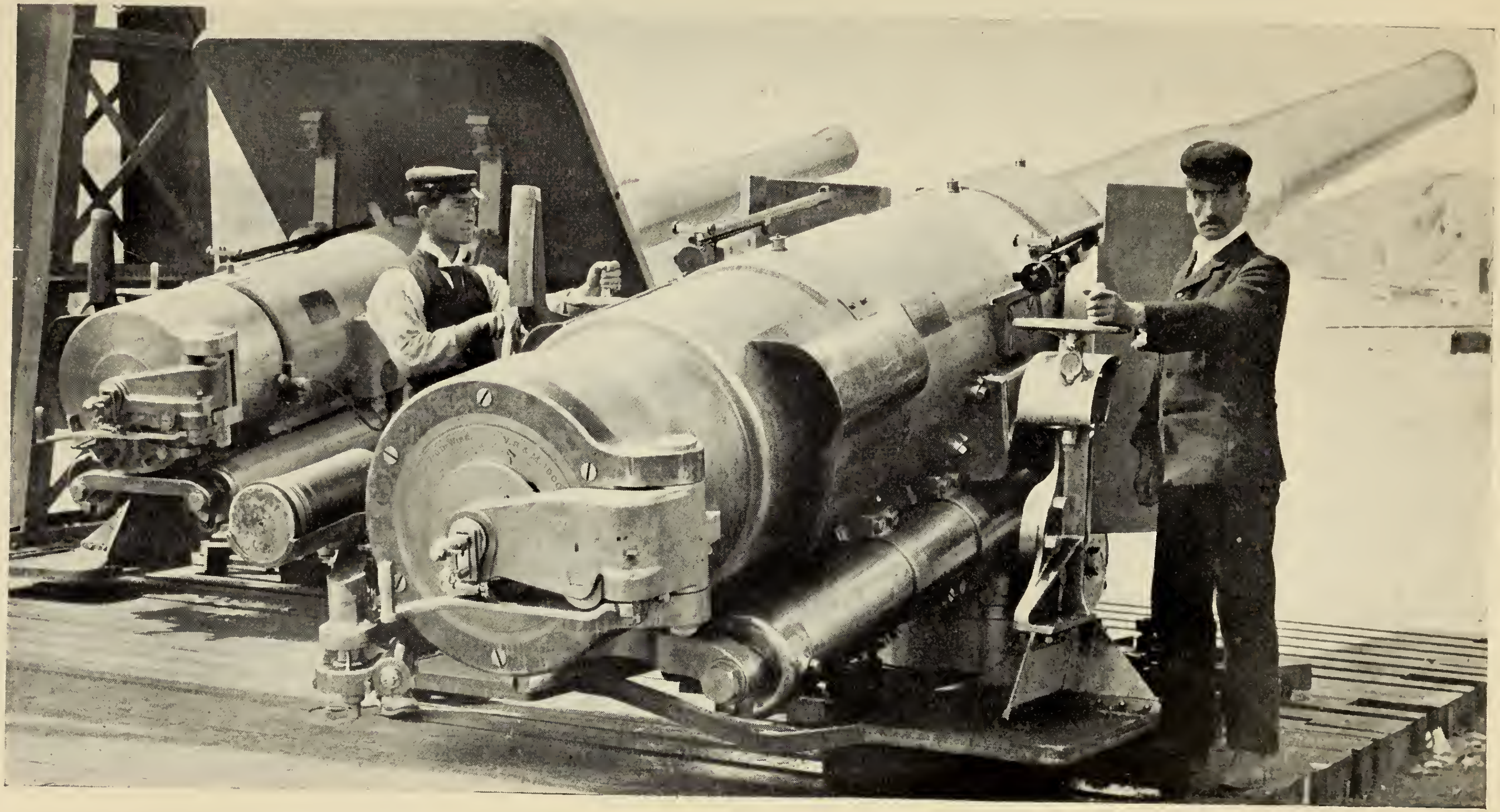


Fig. 33. *6-inch and 7·5-inch Q.F. Guns on Pedestal Mountings.*

NAVAL ORDNANCE.

Fig. 34. *6-inch and 7·5-inch Q.F. Guns on Pedestal Mountings.*

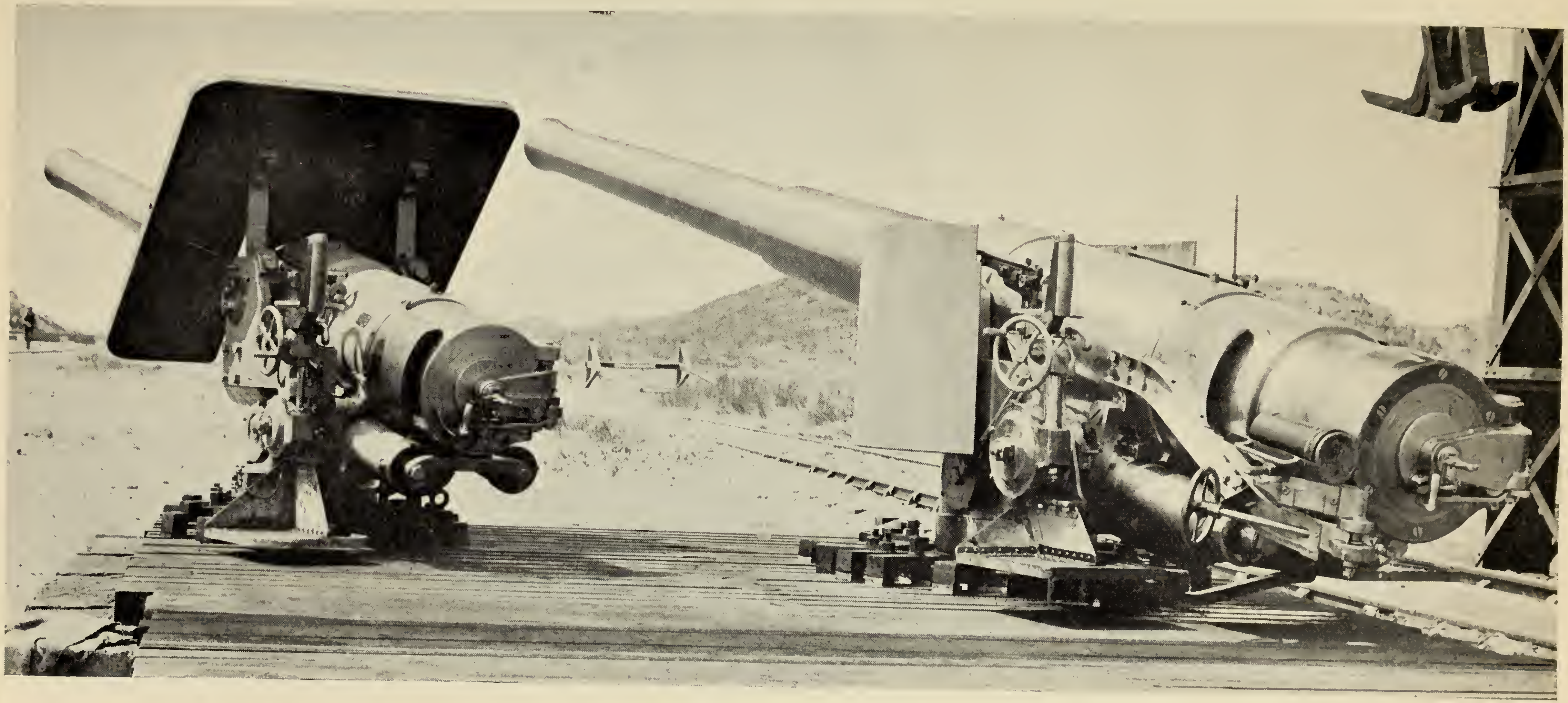
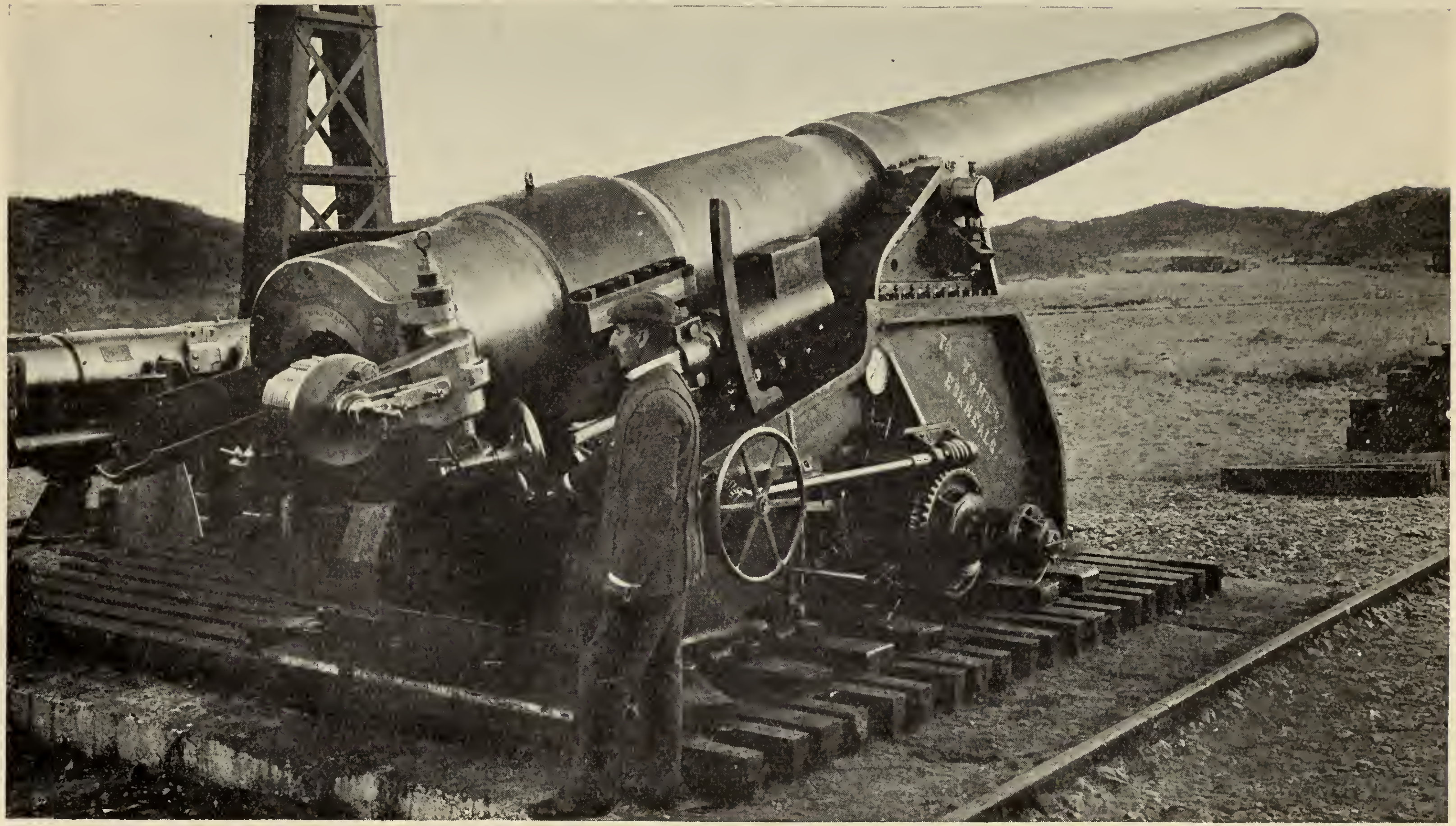


Fig. 35. *9·2-inch B.L. Gun and Mounting.*



Mechanical Engineers 1901.

NAVAL ORDNANCE.

9·2-inch B.L. Gun and Mounting.

Fig. 36.

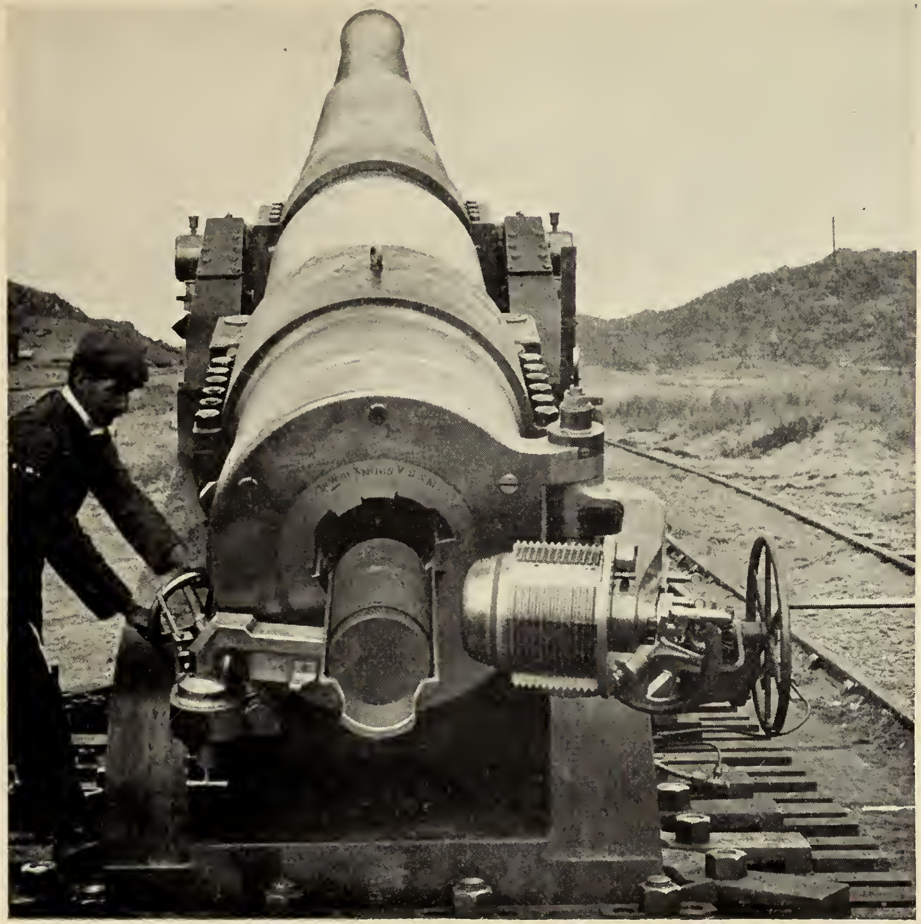
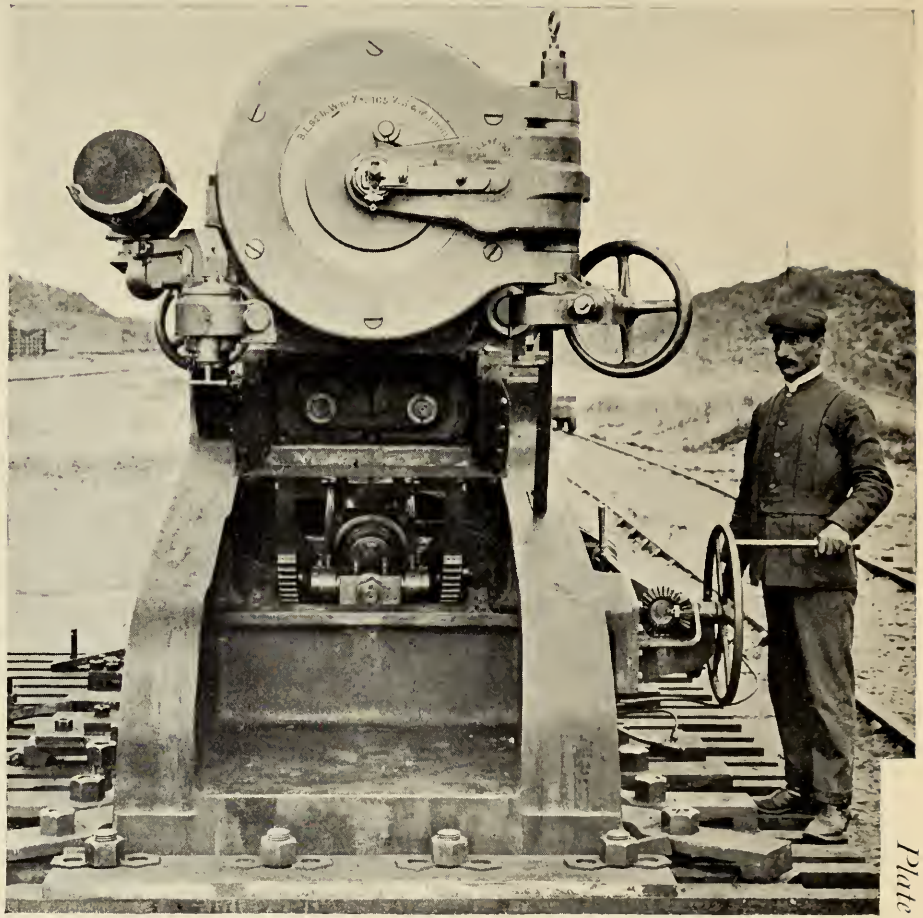


Fig. 37.



NAVAL ORDNANCE.

3-inch (14 Pdr.)
Semi-Automatic Q.F. Gun.
On Cone Mounting.

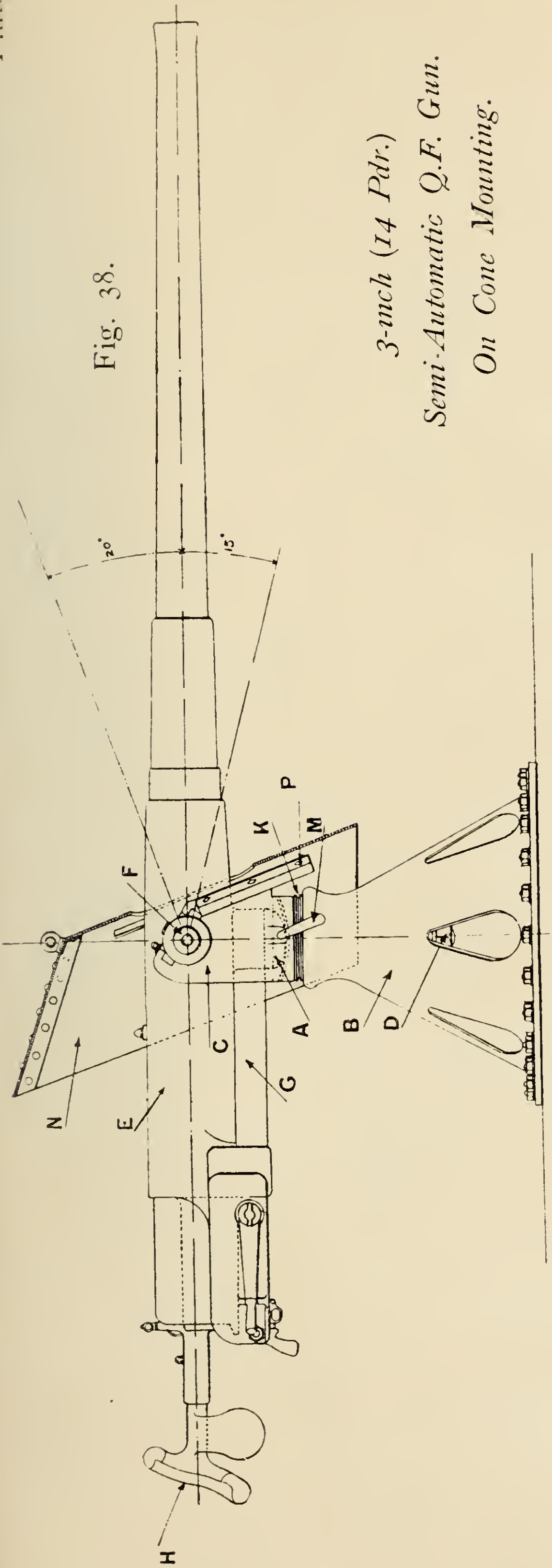


Fig. 38.

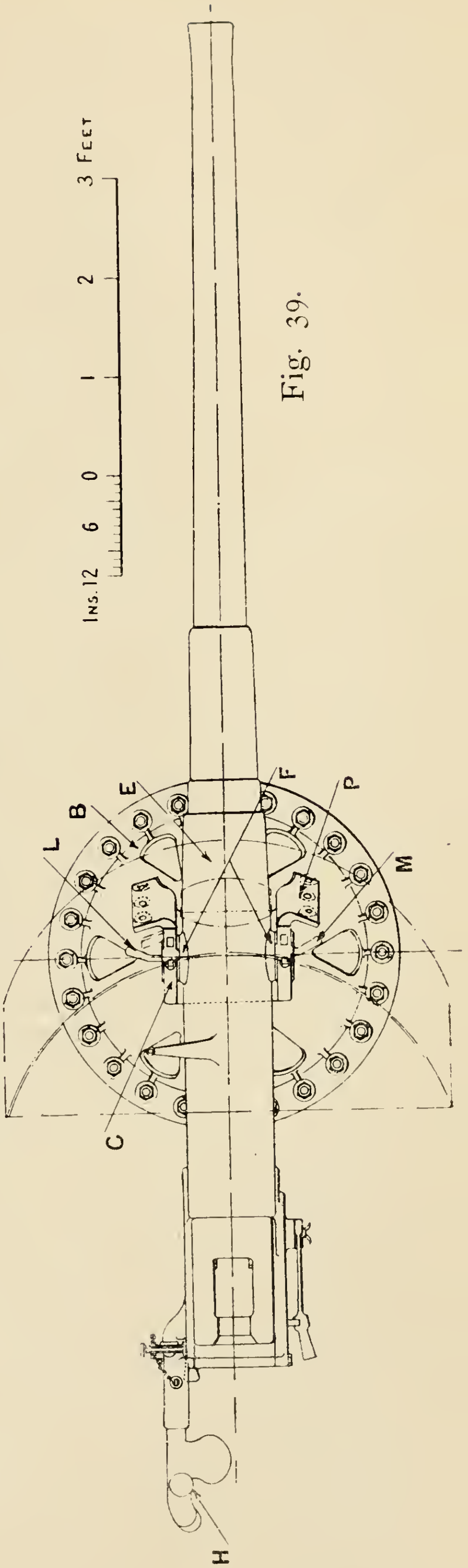
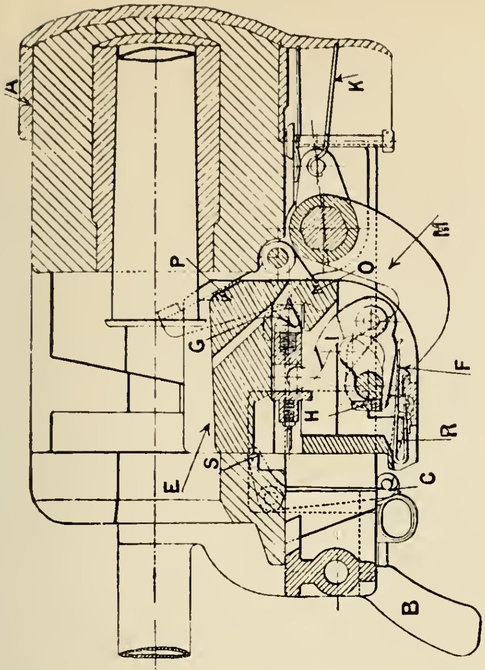


Fig. 39.

Fig. 42.



Mechanism for

3-inch (14 Pdr.) Semi-Automatic Q.F. Gun.

50 Calibres.

Fig. 40.

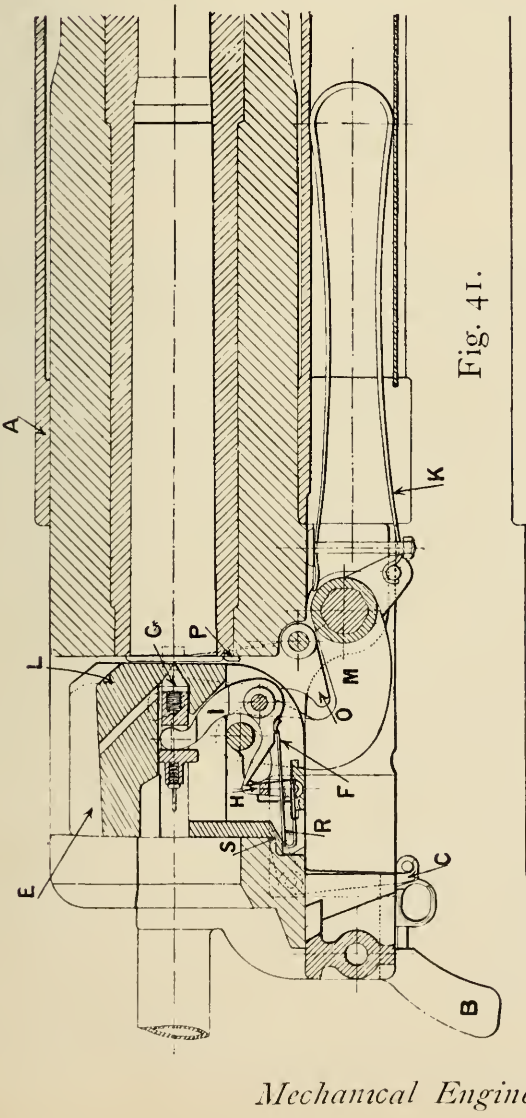


Fig. 41.

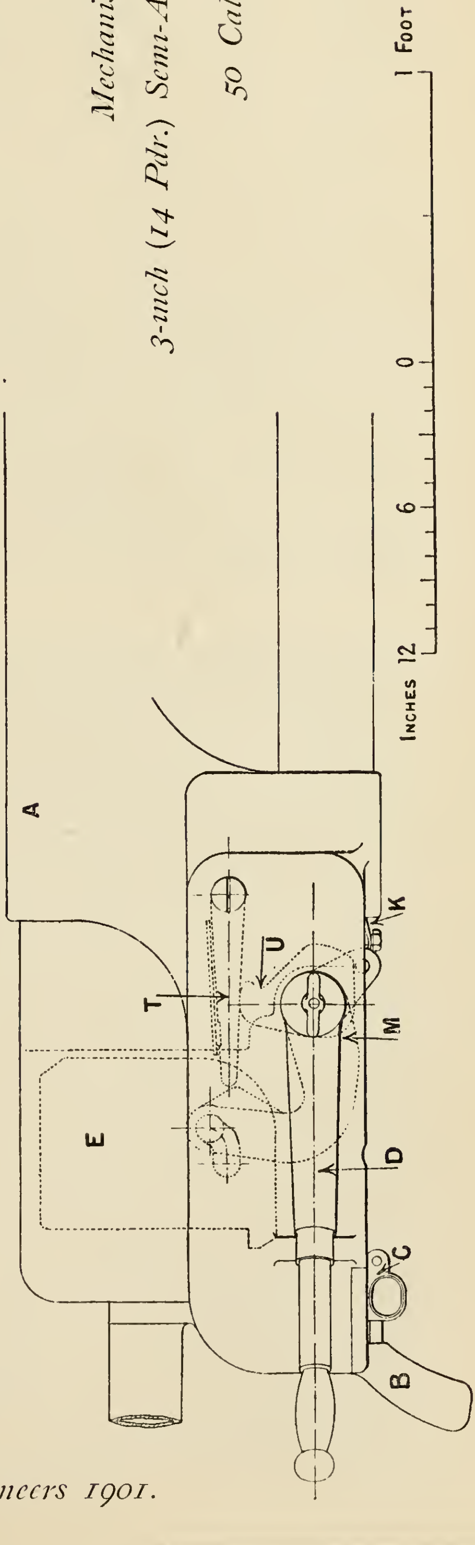


Fig. 43. *3-Pdr. Automatic Gun with Hopper Feed.*

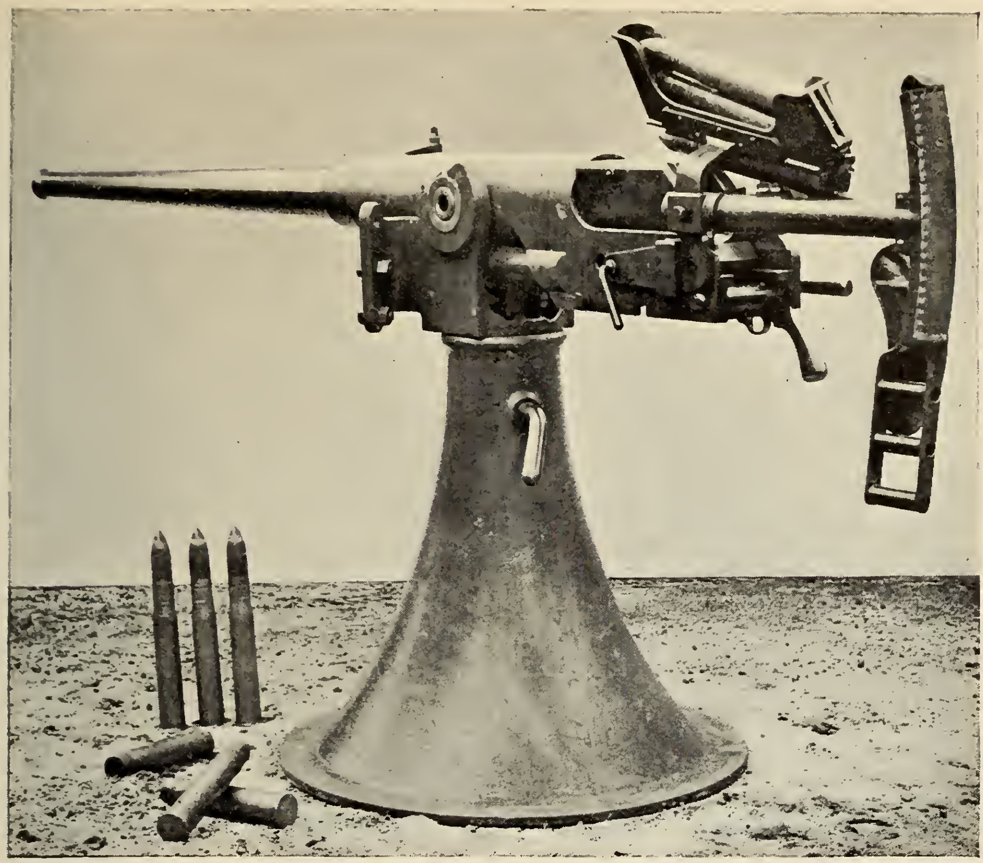
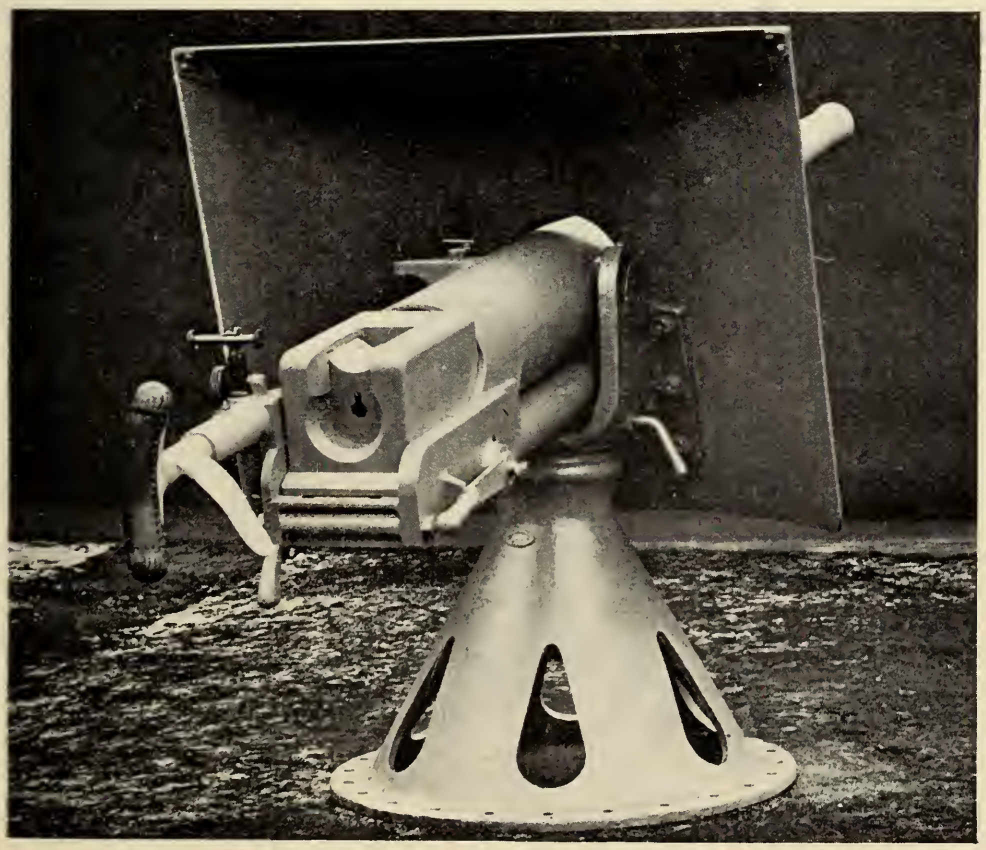


Fig. 44. *14-Pdr. Semi-Automatic Gun.*



47 m/m (3 Pdr.)

Automatic Q.F. Gun.
On Pillar Mounting.

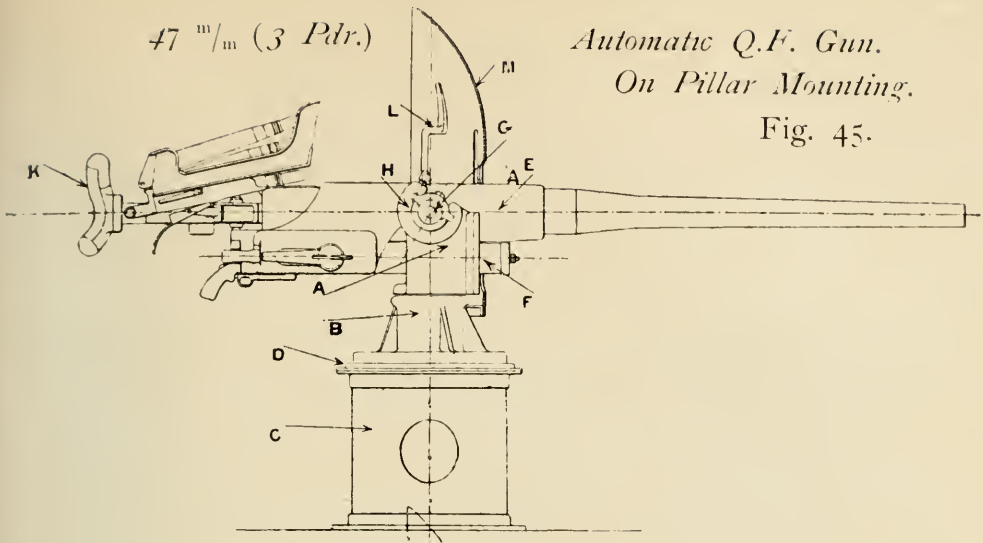


Fig. 45.

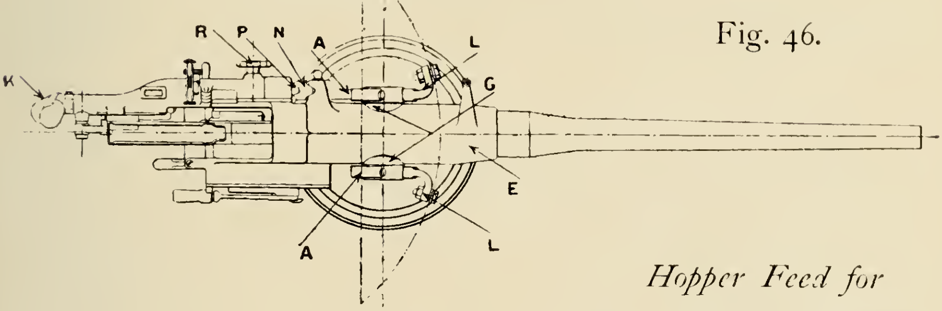


Fig. 46.

Hopper Feed for
3-Pdr. Automatic
Q.F. Gun.

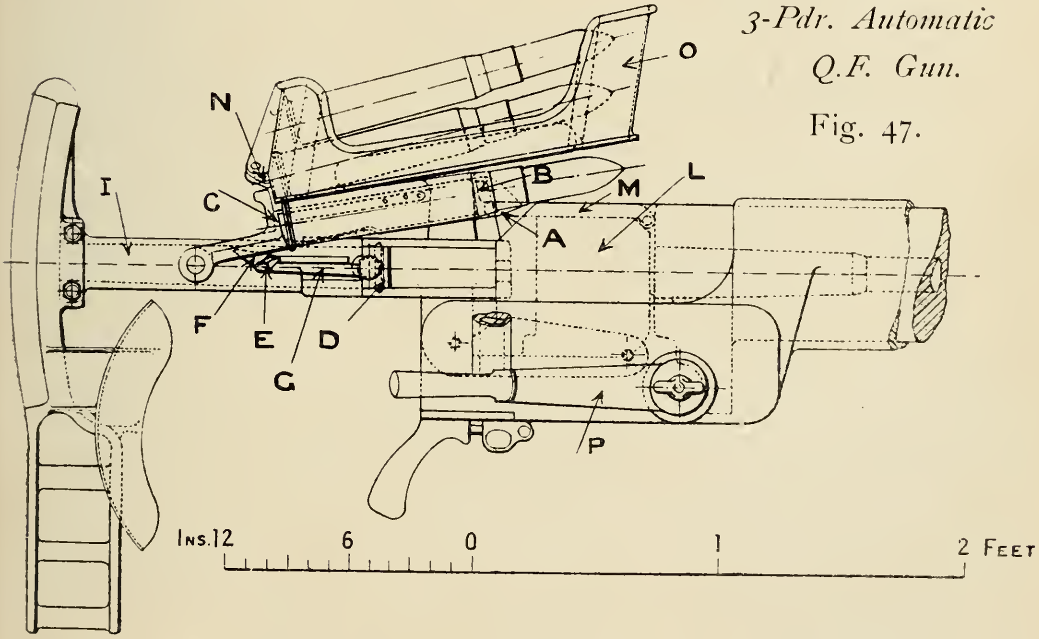


Fig. 47.

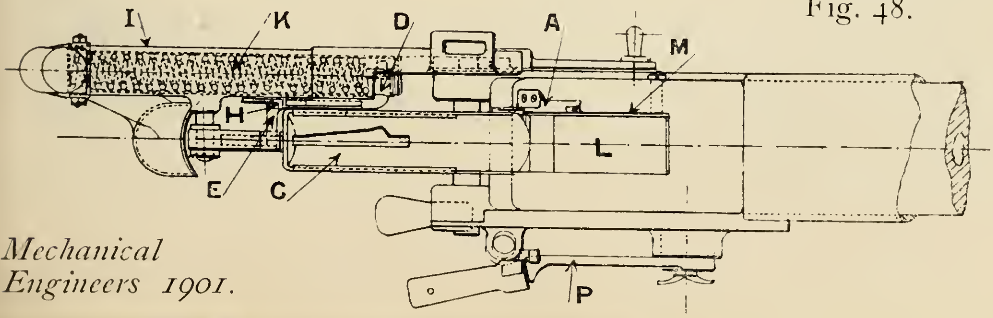


Fig. 48.

Mechanical
Engineers 1901.

Maxim Gun on Quadrupod Mounting.

Fig. 49. *Carrying Position.*

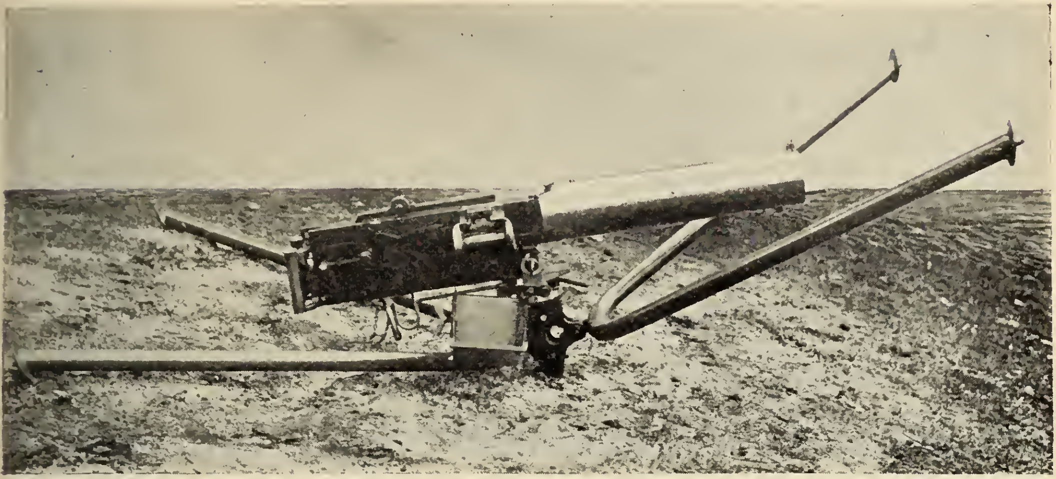


Fig. 50. *Firing Position.*

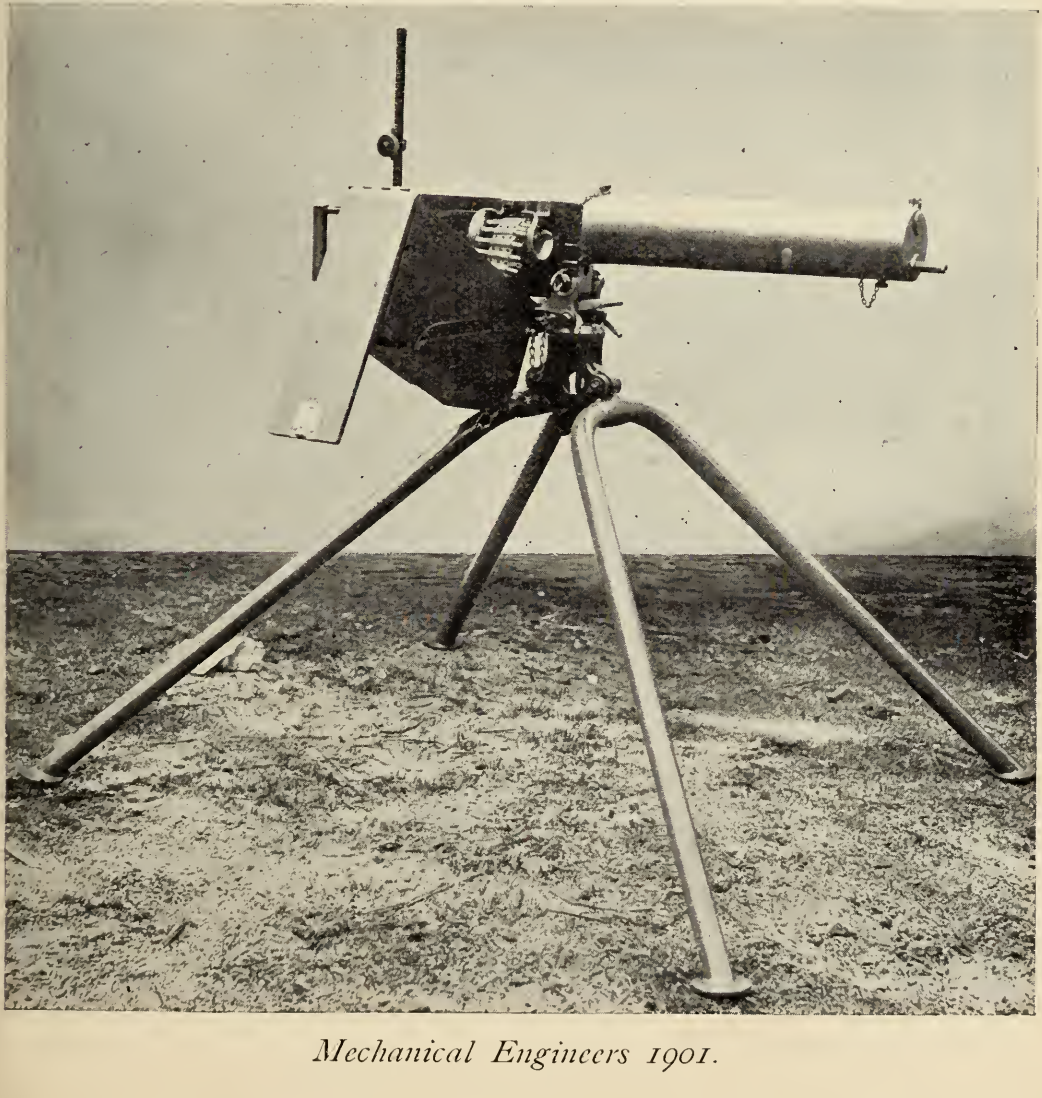
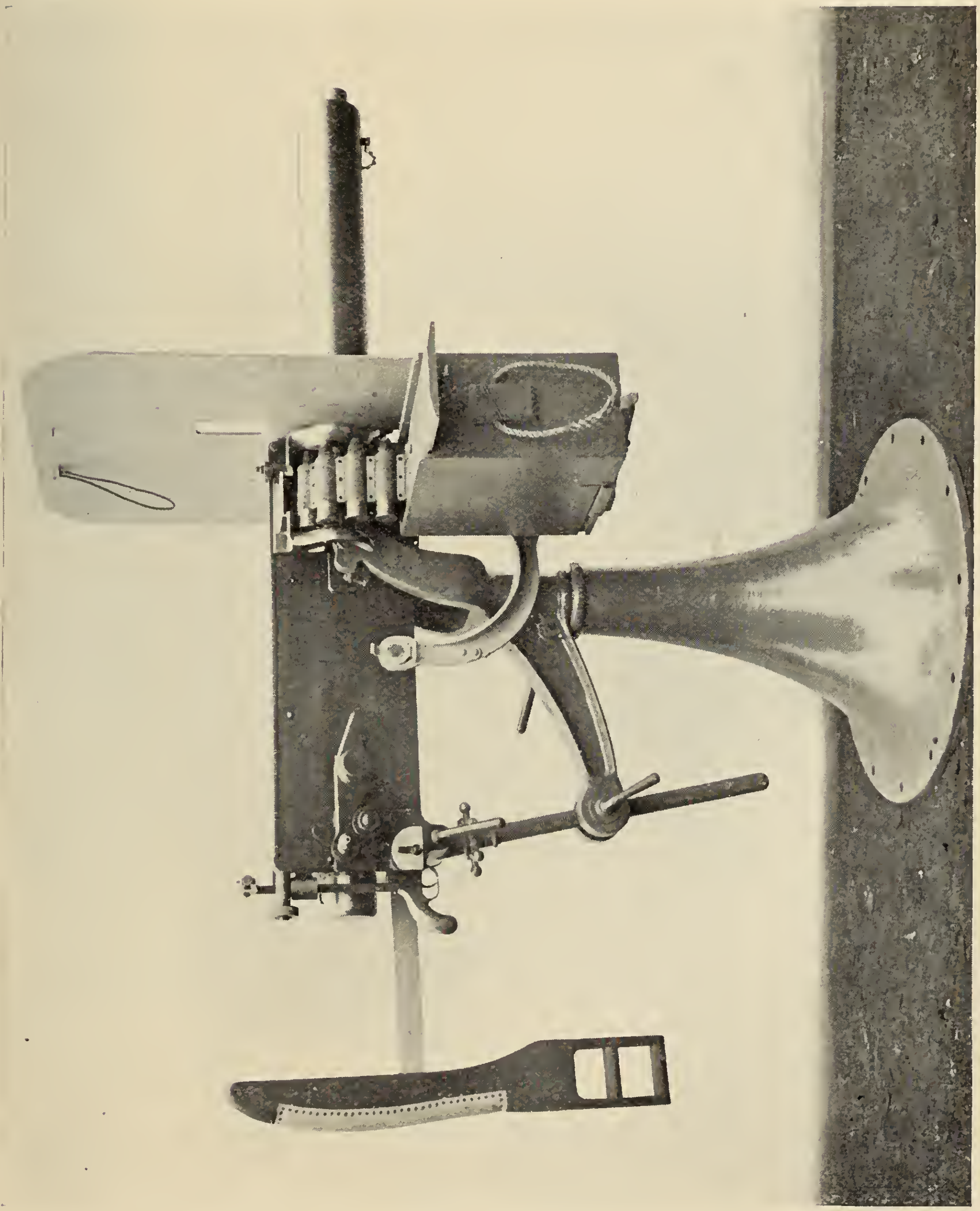


Fig. 51.

37 $^{\text{m}}/_{\text{m}}$ Automatic Gun on Cone Mounting.

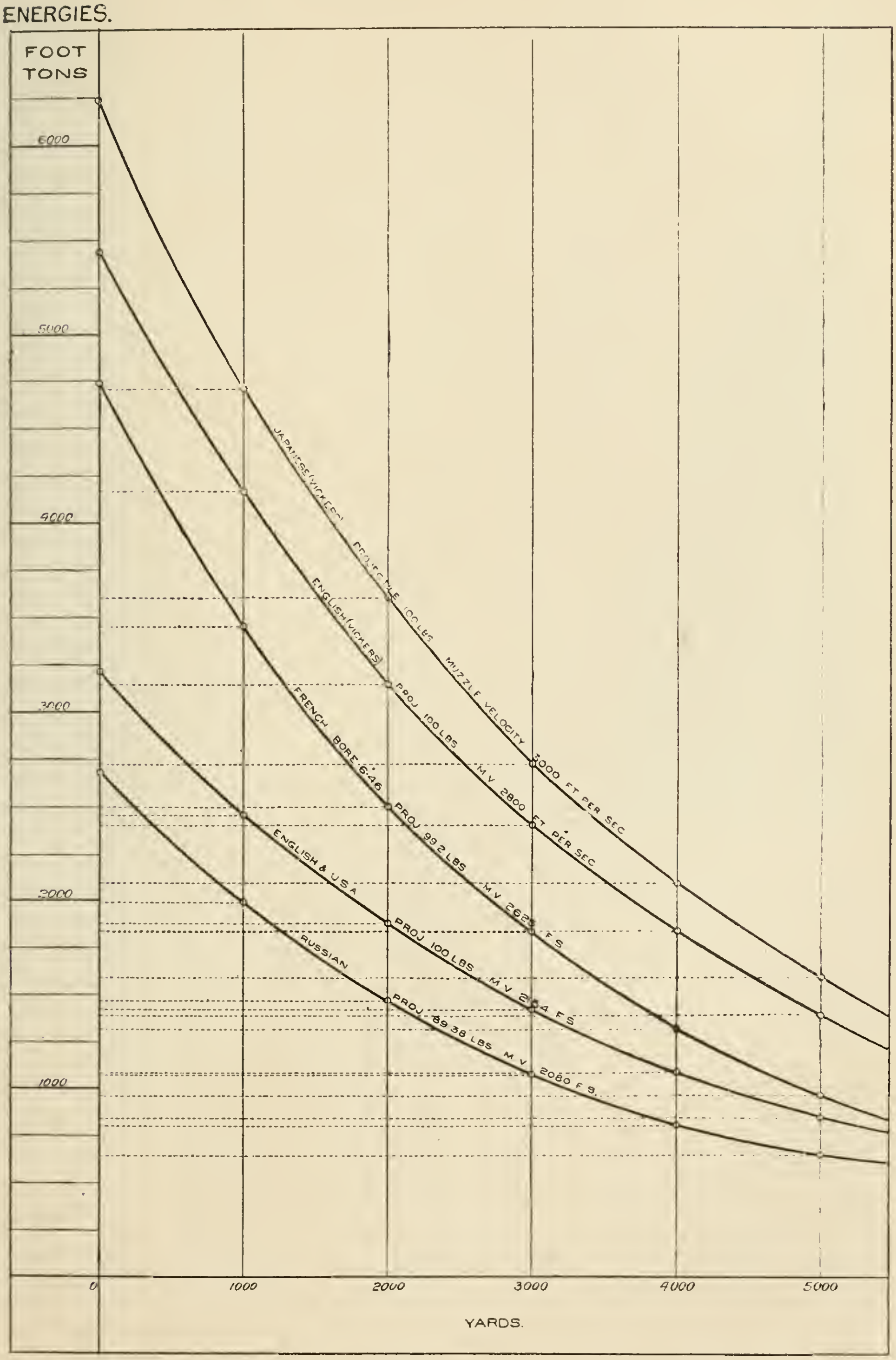


NAVAL ORDNANCE.

Plate 91.

Fig. 52.

Curve showing Comparative Energies of various 6-inch Guns.



Mechanical Engineers 1901.

Fig. 53. *Comparison of Dangerous Space, using 6-inch Service Guns.*

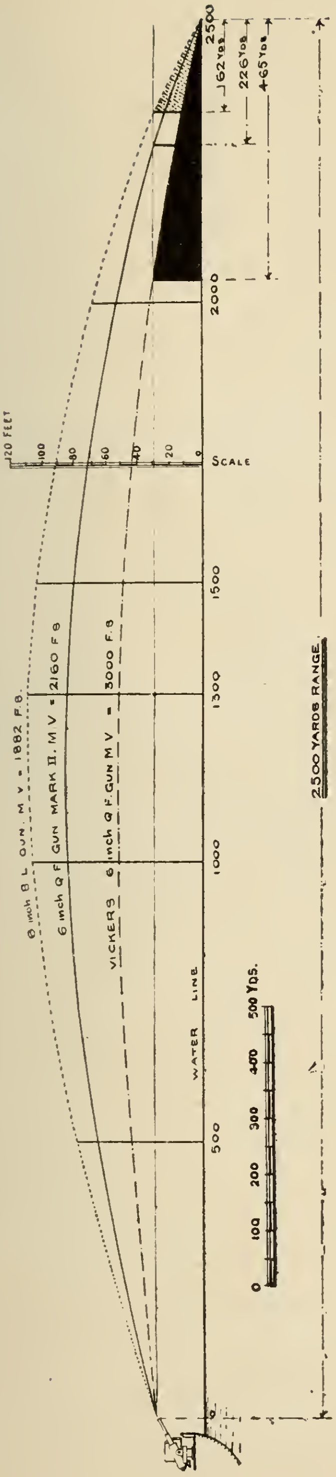


Fig. 54. *12-inch B.L. Gun.*

Comparison of Dangerous Space with M.V.'s. 2,500 and 2,700 F.S.

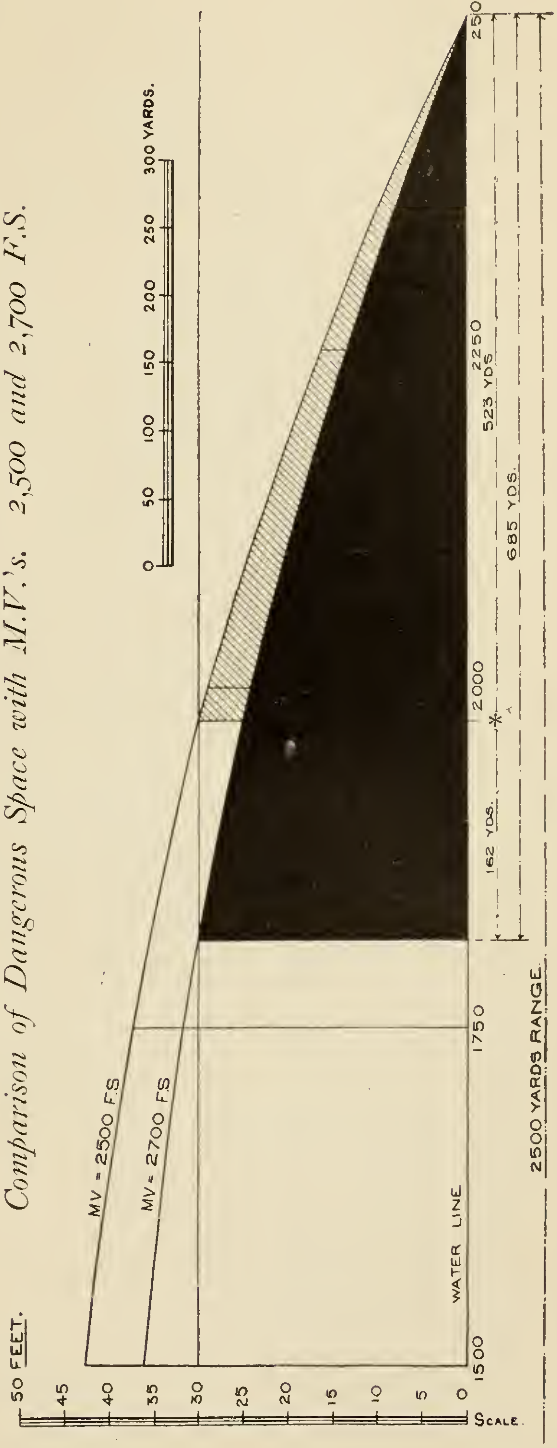
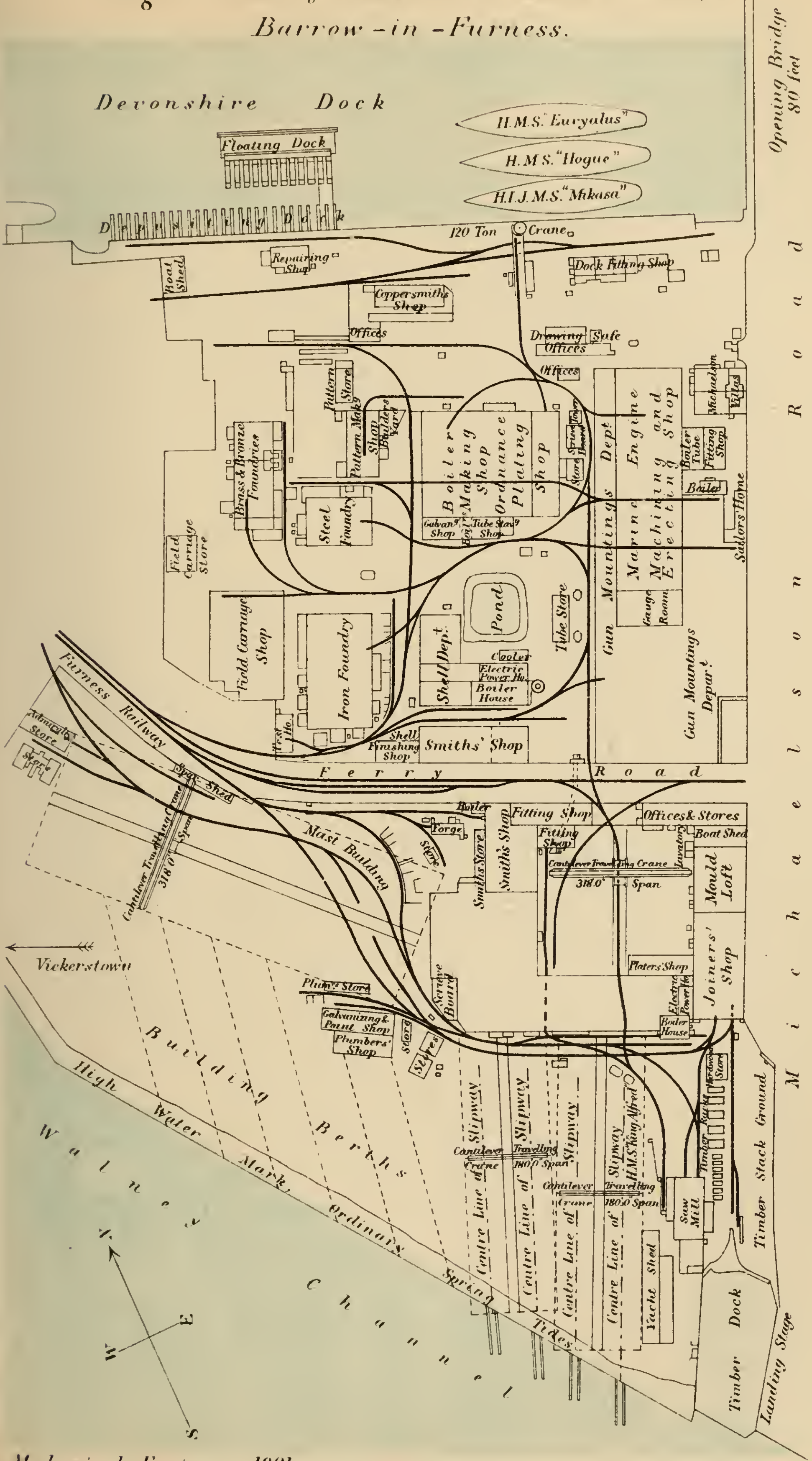


Fig. 1. *Plan of Naval Construction Works, Barrow-in-Furness.*



SHIPBUILDING WORKS.

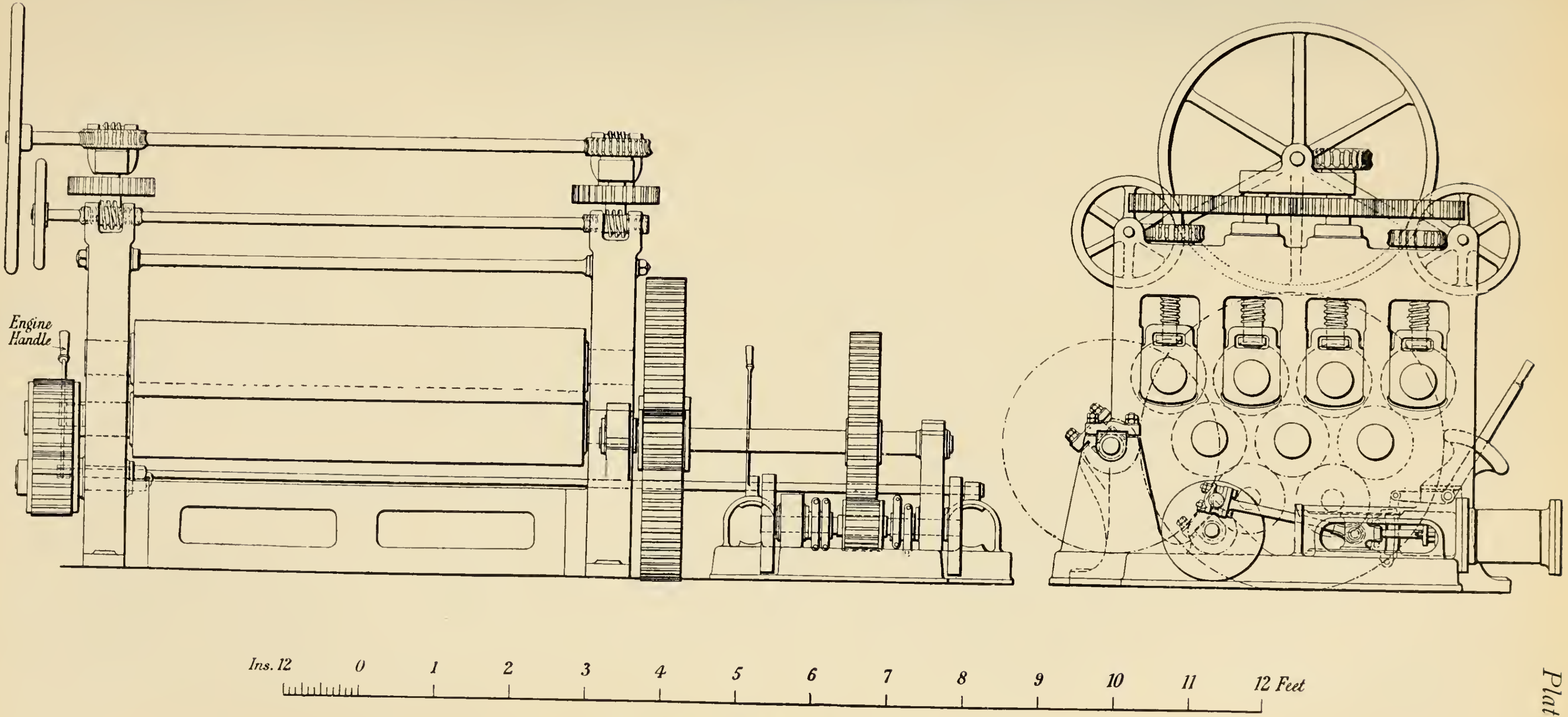


Fig. 5. *Plate Straightening Rolls.*

SHIPBUILDING WORKS.

Hydraulic Benders and Flangers.

Fig. 6. Fig. 7.

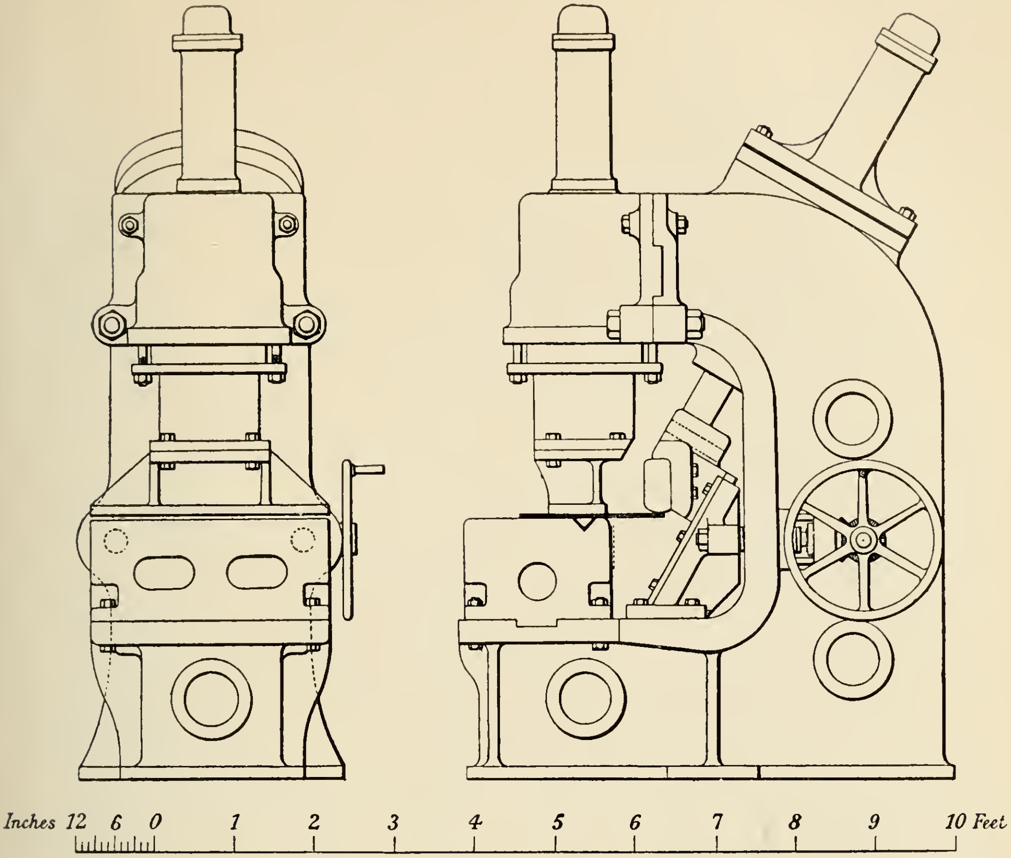
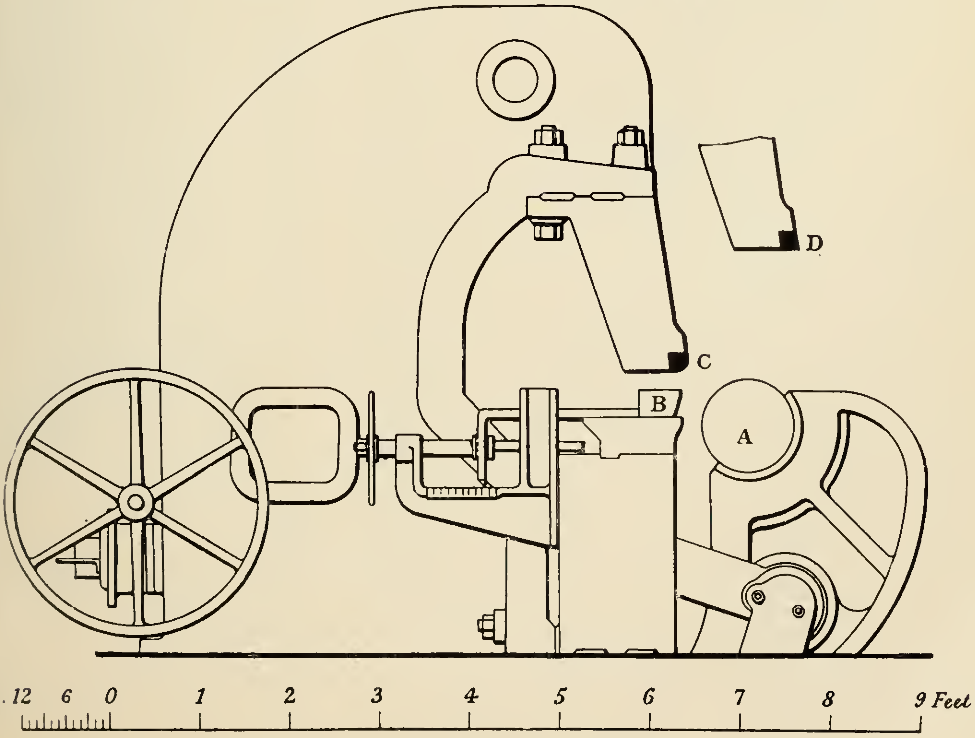


Fig. 8. *Keel Plate Bending Machine.*



SHIPBUILDING WORKS.

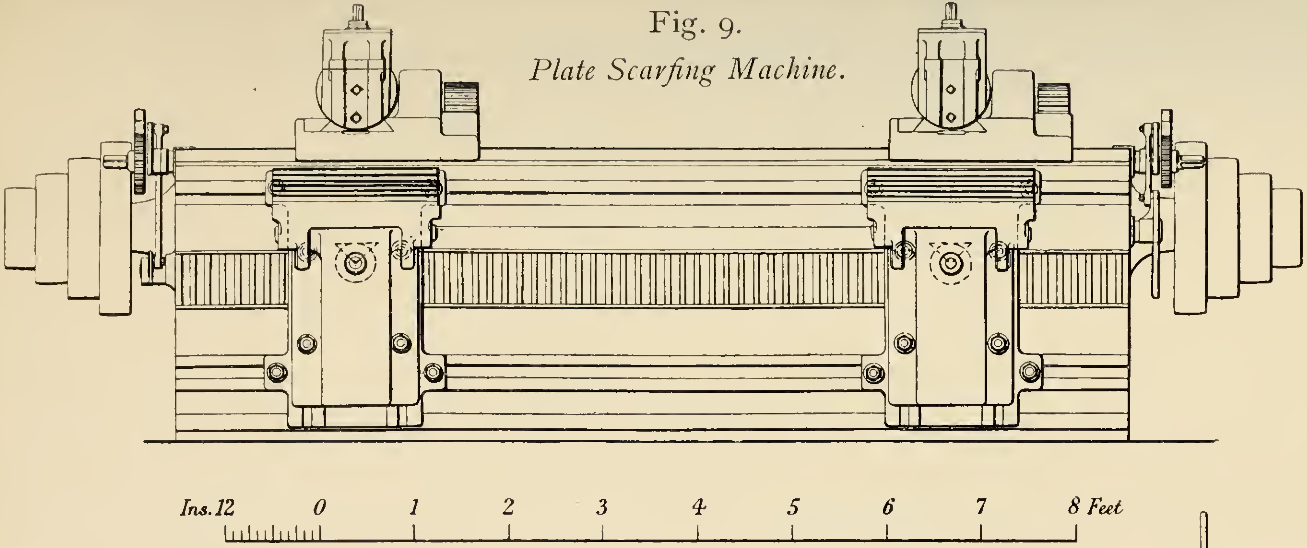


Fig. 9.

Plate Scarfing Machine.

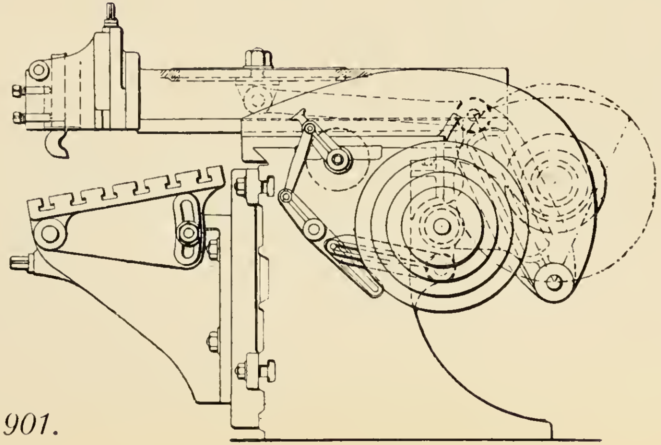


Fig. 10.

End view of above Machine.

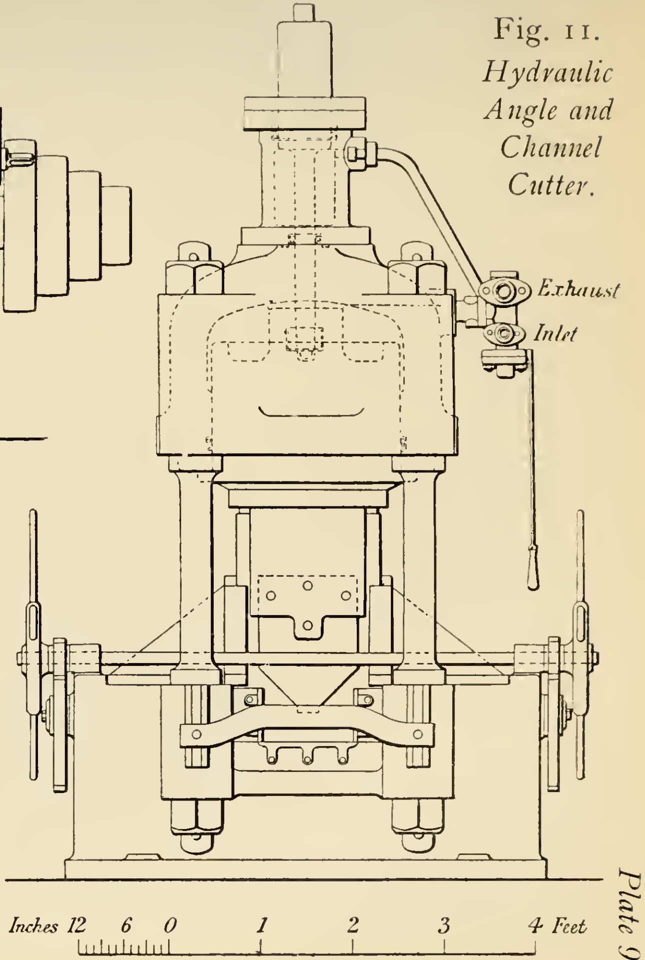


Fig. 11.

Hydraulic Angle and Channel Cutter.

Plate 99.

SHIPBUILDING WORKS.

Cranes for Ship-Berths.

Figs. 12 and 13. *Gantry, Harland and Wolff, Belfast.*

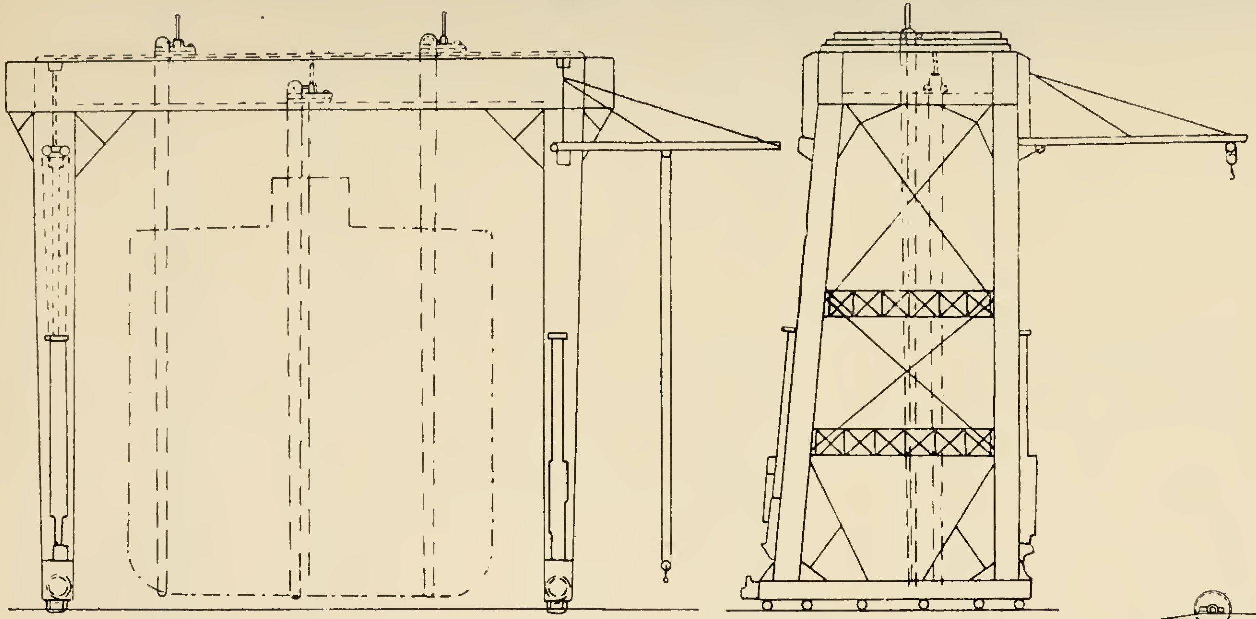


Fig. 14. *San Francisco.*
(Union Iron Works.)

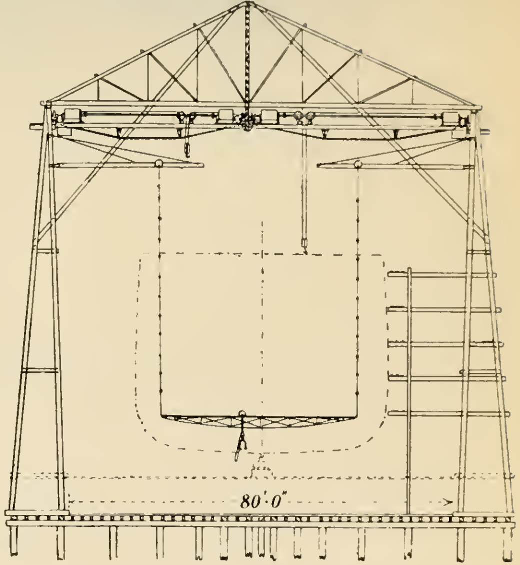


Fig. 15. *Travelling Crabs, overlapping.* *(Wellman Seaver.)*

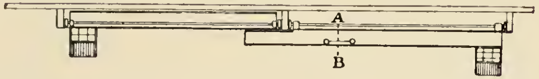
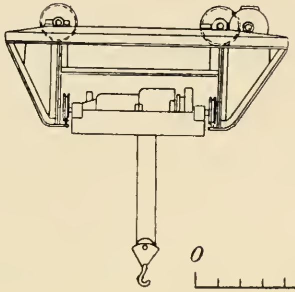


Fig 16.

Section on A.B., Fig. 15.
showing Trolley Runway.



Scale for Figs. 12 to 15, and 17 to 19, Plate 101.

0 50 100 150 200 Feet

0 5 10 Feet

Mechanical Engineers 1901.

Fig. 20. *Cantilever Cranes for Ship-Berths. (Brown), Barrow.*

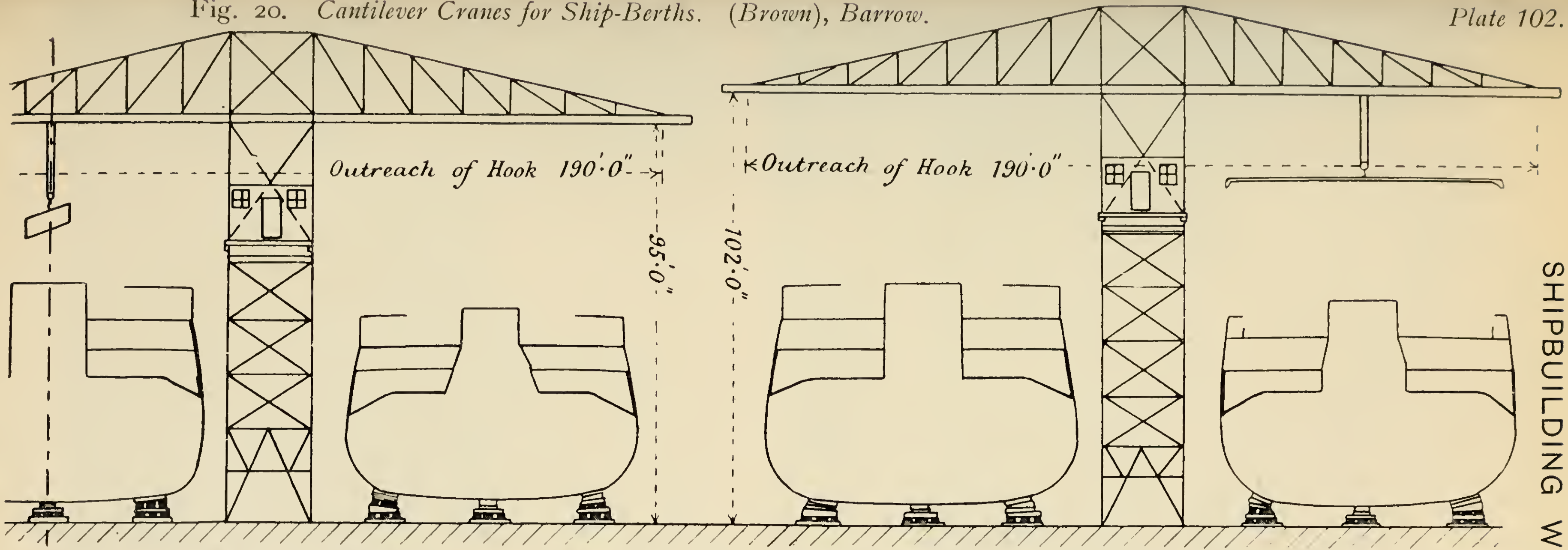
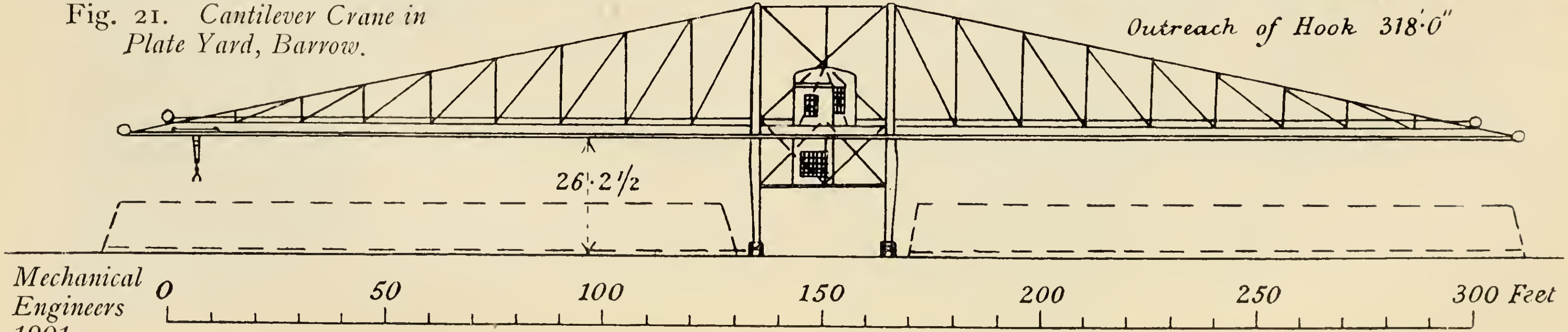


Fig. 21. *Cantilever Crane in Plate Yard, Barrow.*



Mechanical Engineers 1901.

Fig. 22. *Centre Bay of Ship-Berth Crane, Fig. 20.*

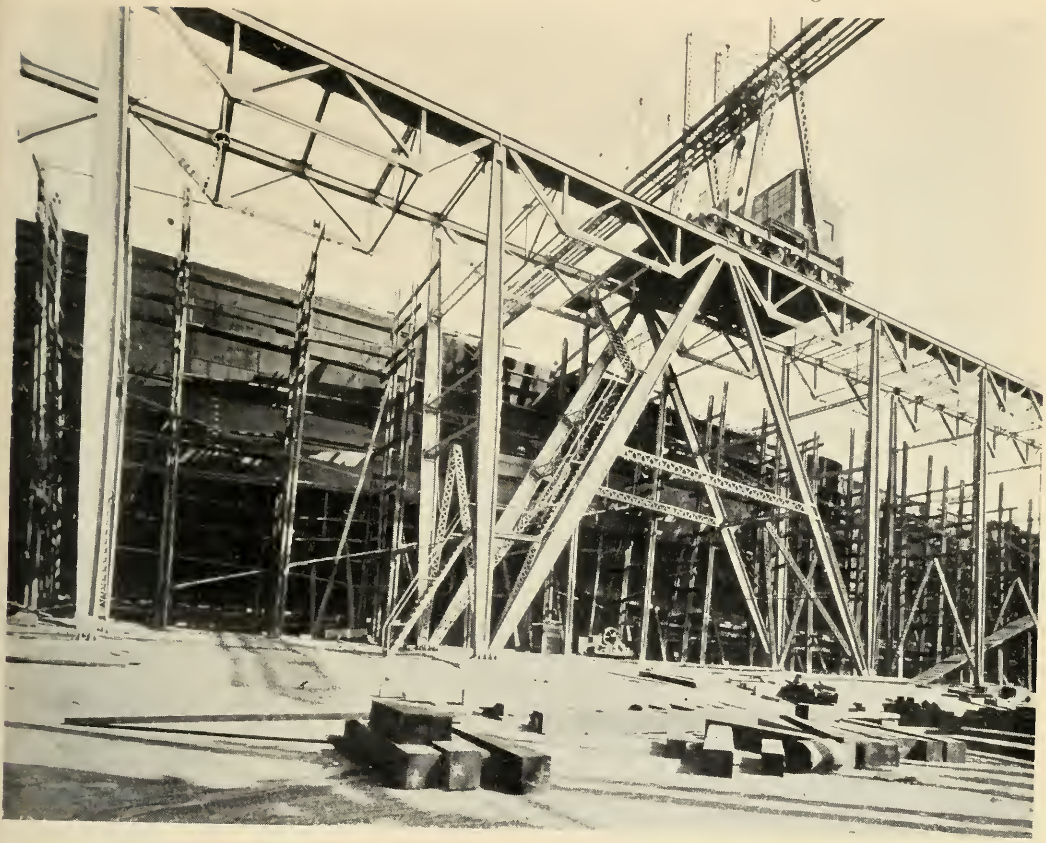


Fig. 23. *Crab for above.*

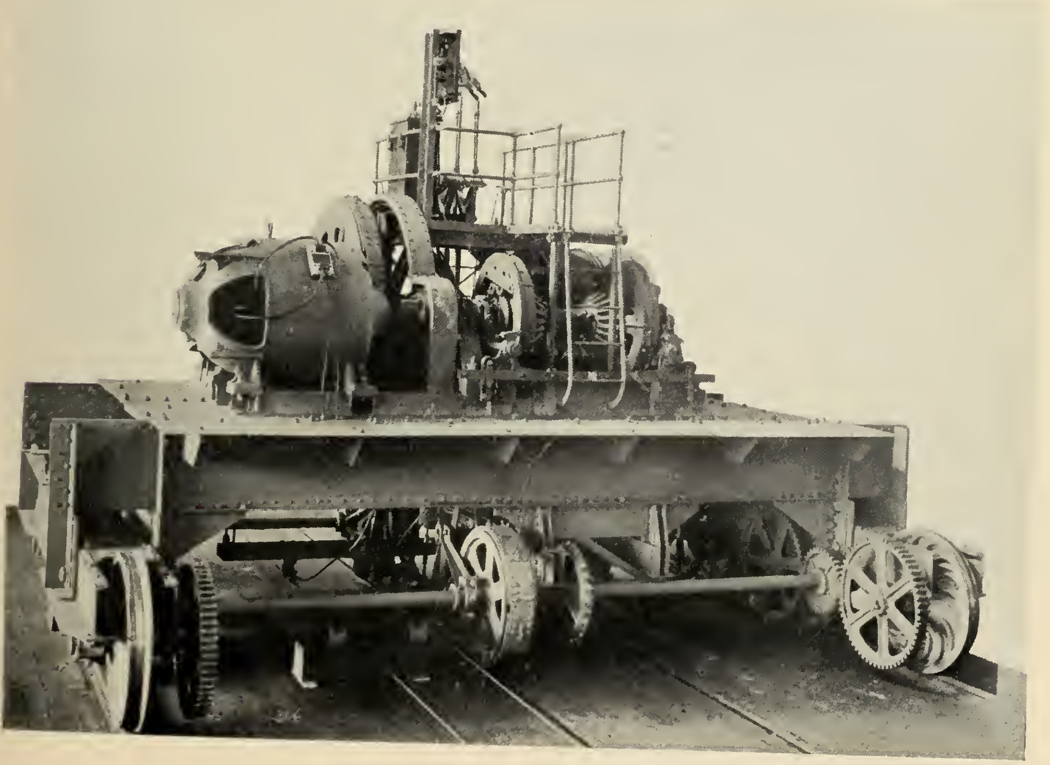


Fig. 24. *Ship Berth Cantilever Crane, Barrow.*

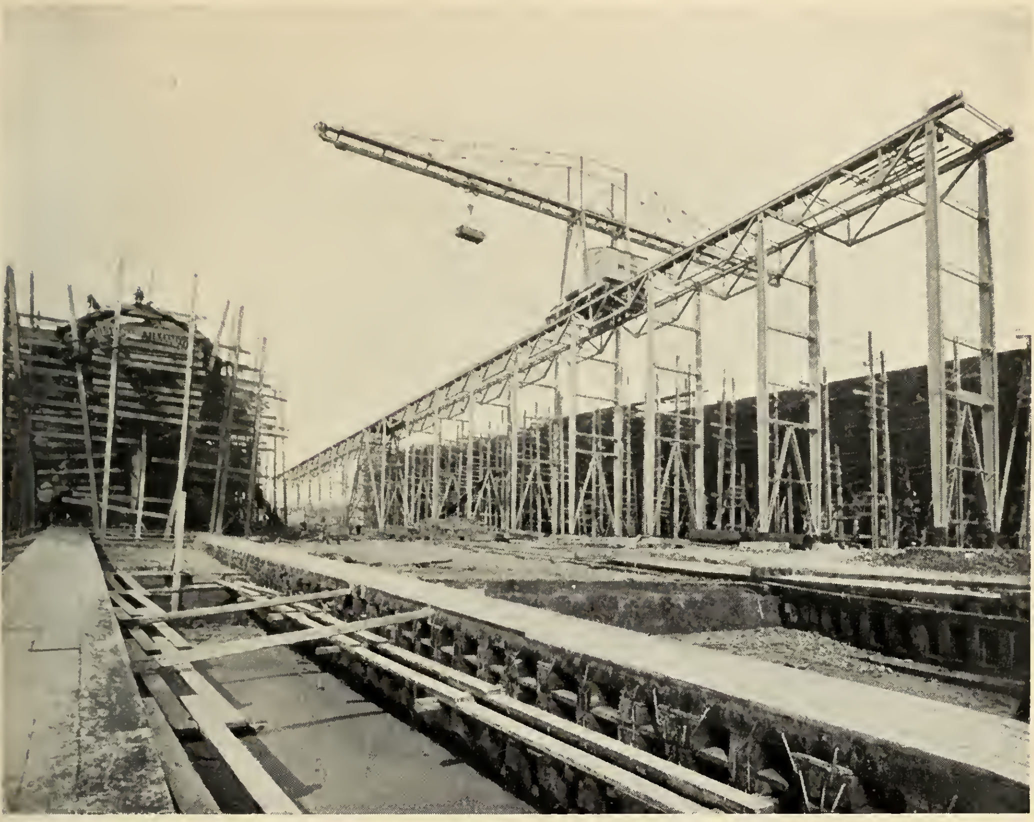


Fig. 25. *Yard Crane for Dealing with Material. (Brown.)*

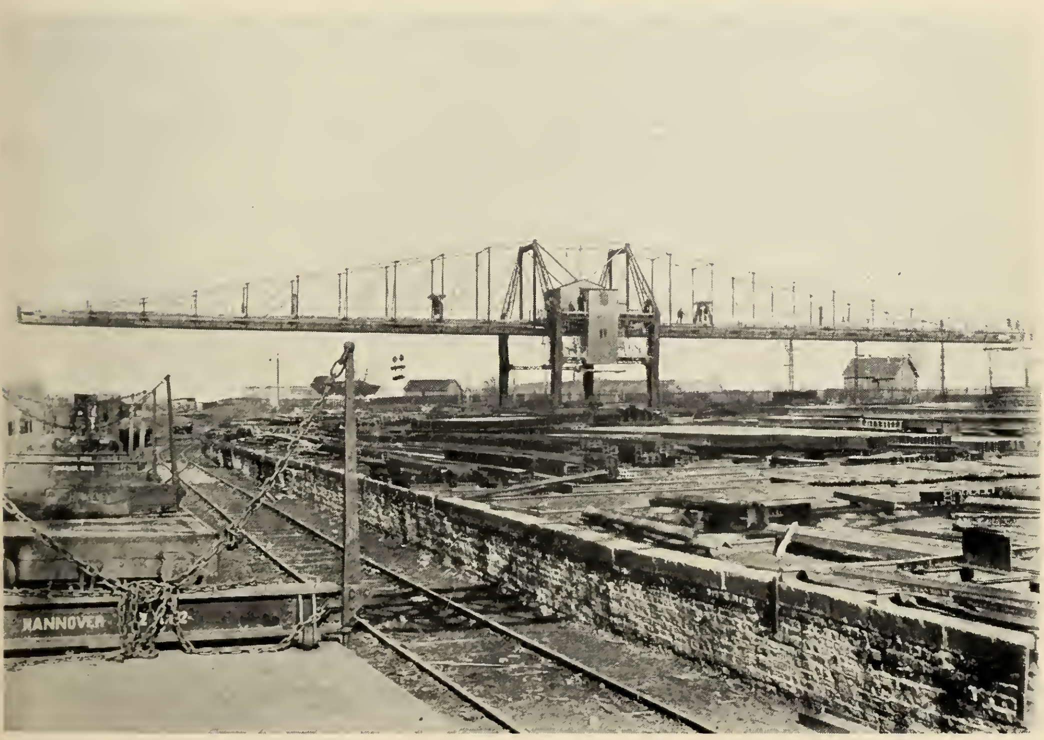
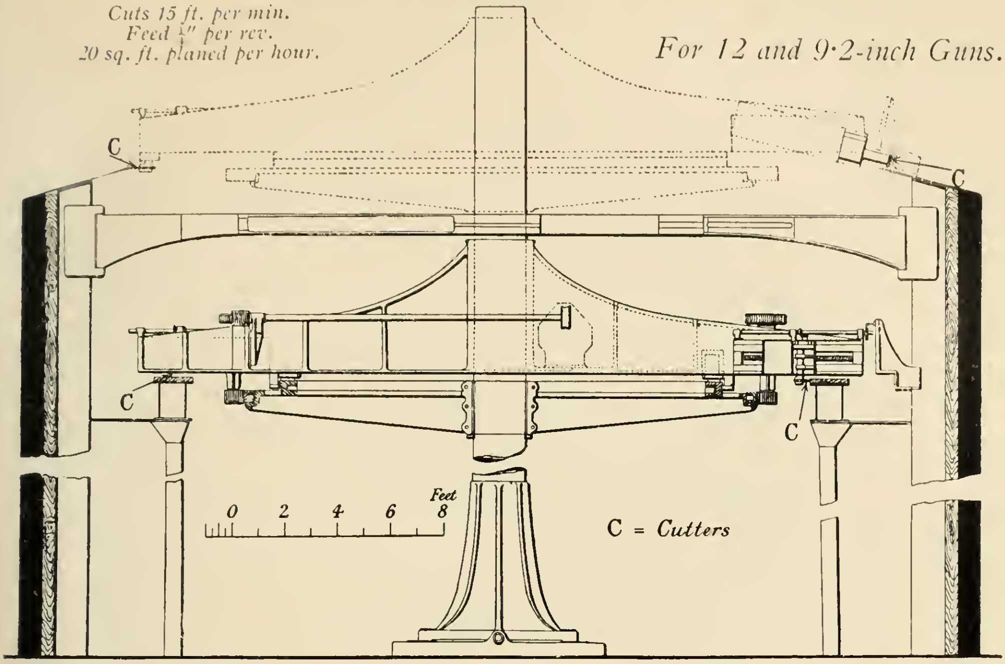


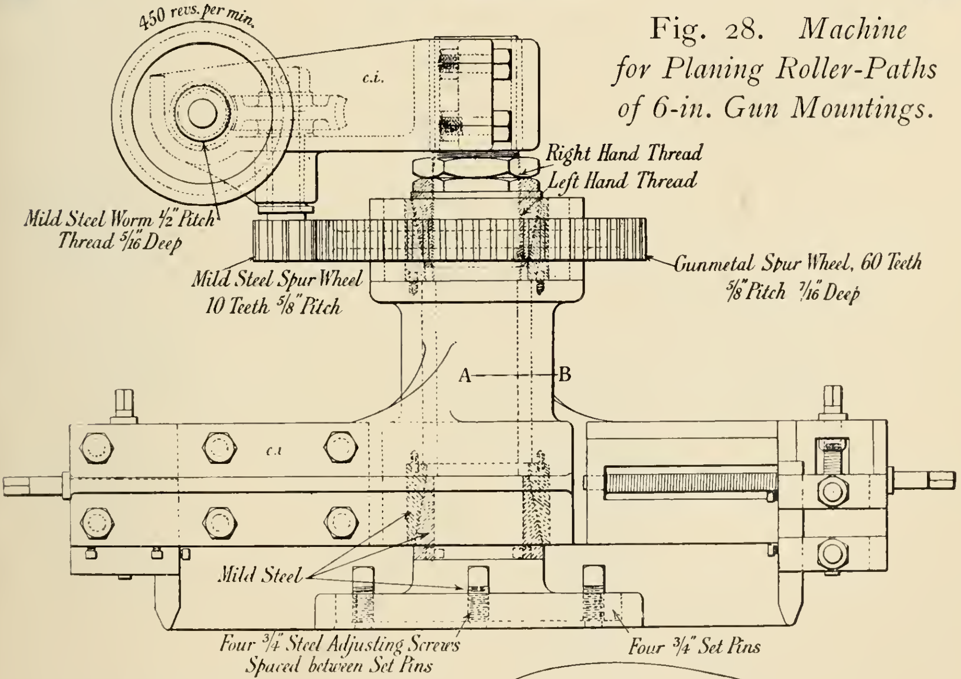
Fig. 27. *Machine for Planing Gun-Roller-Paths on Barbettes.*



Cuts 15 ft. per min.
Feed ½" per rev.
20 sq. ft. planed per hour.

For 12 and 9·2-inch Guns.

Fig. 28. *Machine for Planing Roller-Paths of 6-in. Gun Mountings.*


450 revs. per min.
c.i.
Right Hand Thread
Left Hand Thread
Mild Steel Worm ½" Pitch Thread 5/16" Deep
Mild Steel Spur Wheel 10 Teeth 5/8" Pitch
Gunmetal Spur Wheel, 60 Teeth 5/8" Pitch 7/16" Deep
A
B
c.i
Mild Steel
Four ¾" Steel Adjusting Screws Spaced between Set Pins
Four ¾" Set Pins

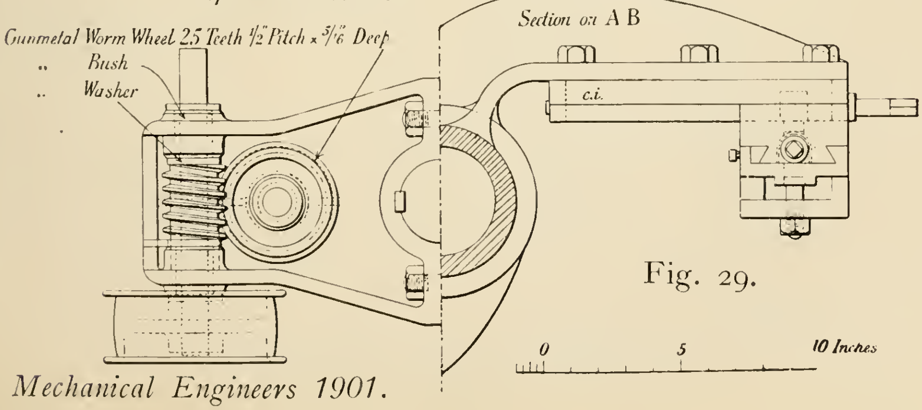


Fig. 29.

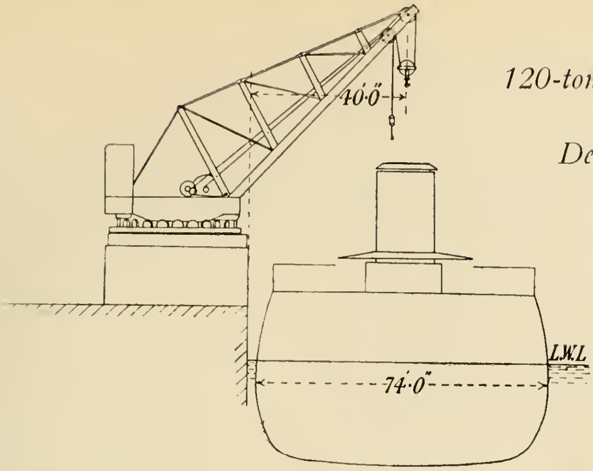


Fig. 30.
120-ton Hydraulic Crane.
(Vickers),
Devonshire Dock,
Barrow.

Fig. 31. *100-ton Revolving Crane. (Benrath), Bremen.*

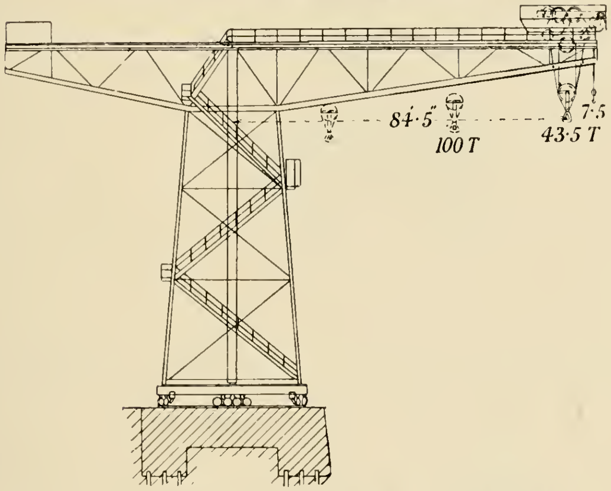


Fig. 32. *150-ton Revolving Crane. (Duisburg), Kiel.*

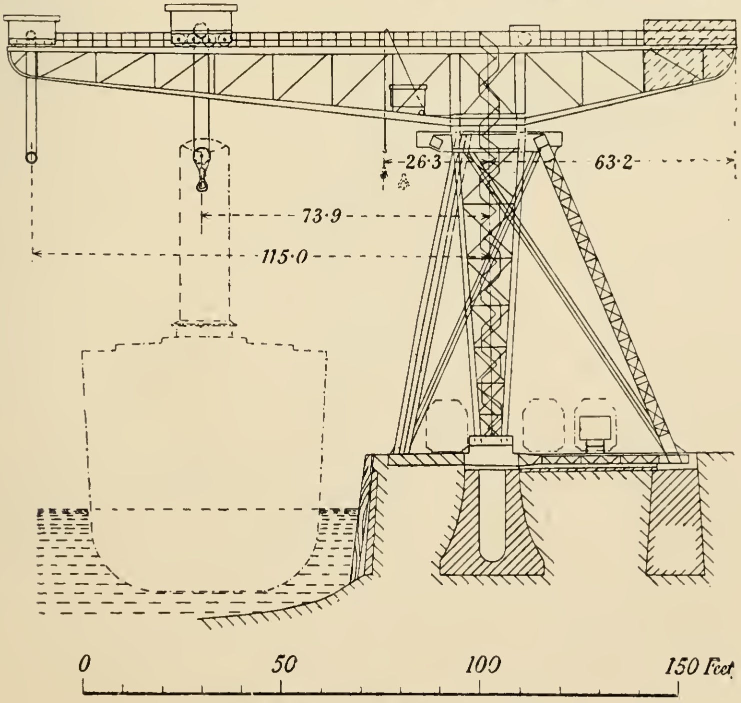


Fig. 33. *150-ton Crane. (Benrath), Bremerhaven.*

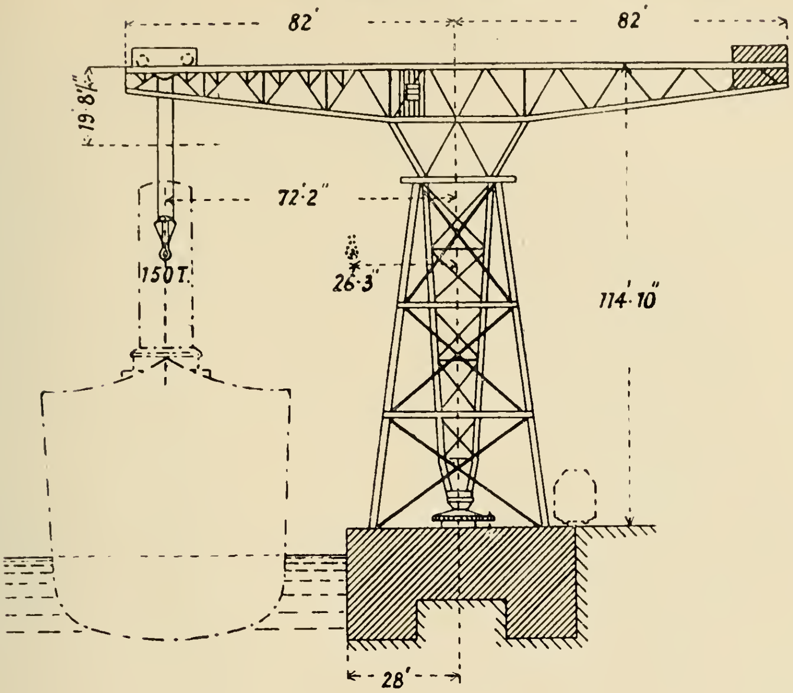
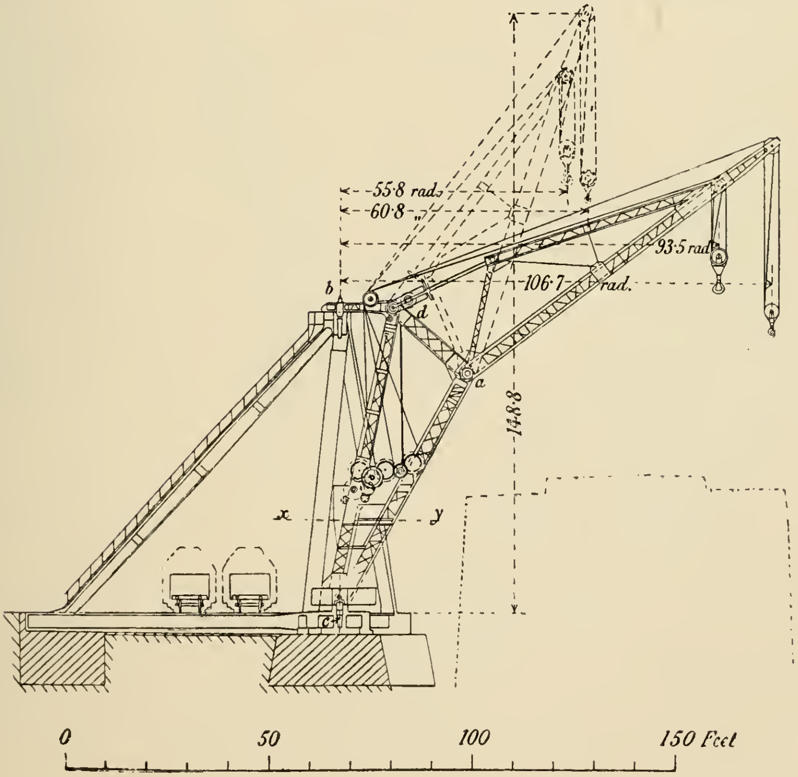
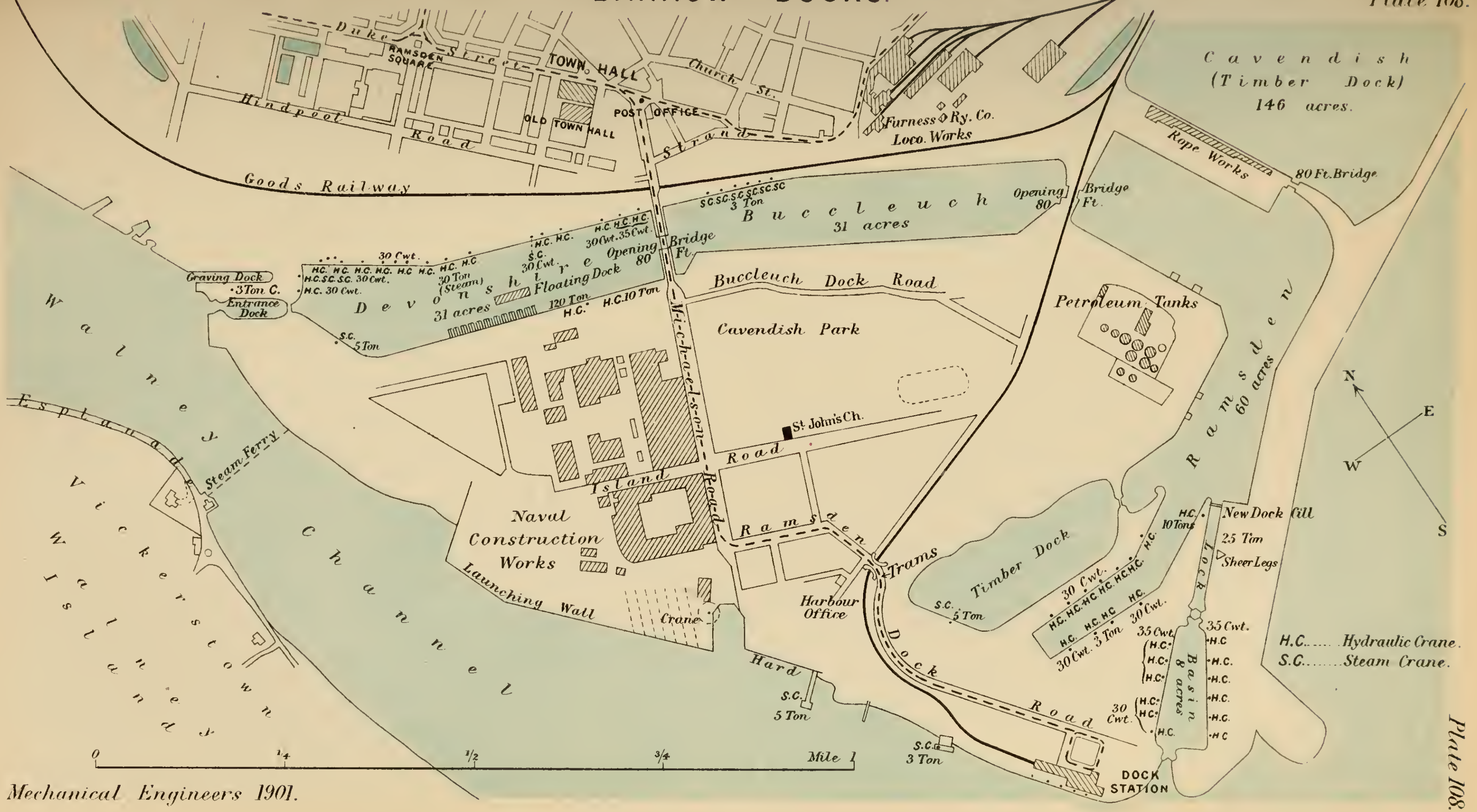


Fig. 34. *100-ton Derrick Crane. (Duisburg), for Blohm and Voss.*

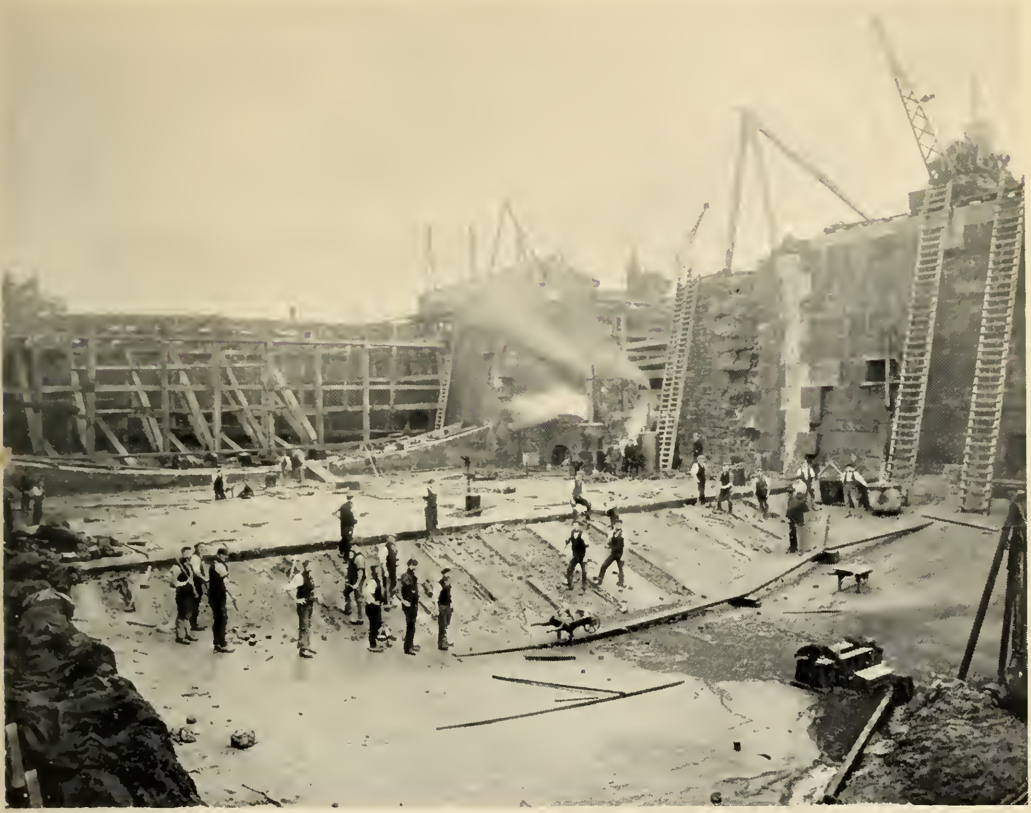


BARROW DOCKS.

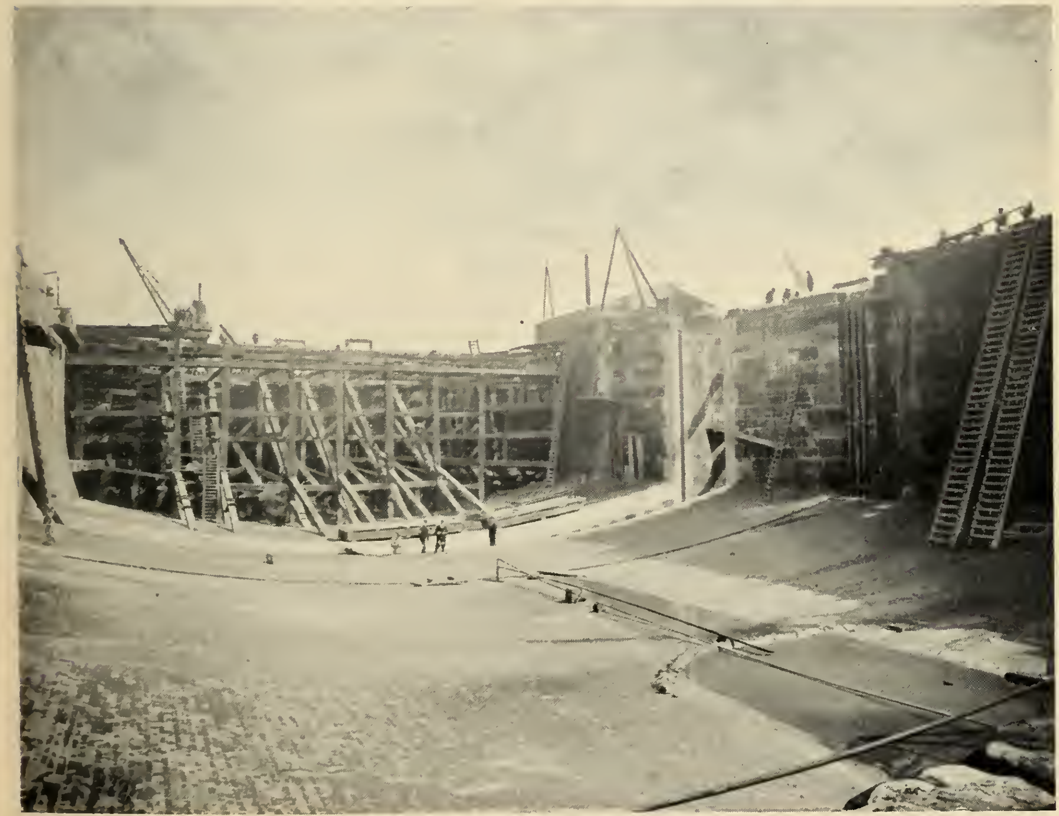


Mechanical Engineers 1901.

100-ft. Lock, 18 December, 1900. Showing Old Cill to be removed.



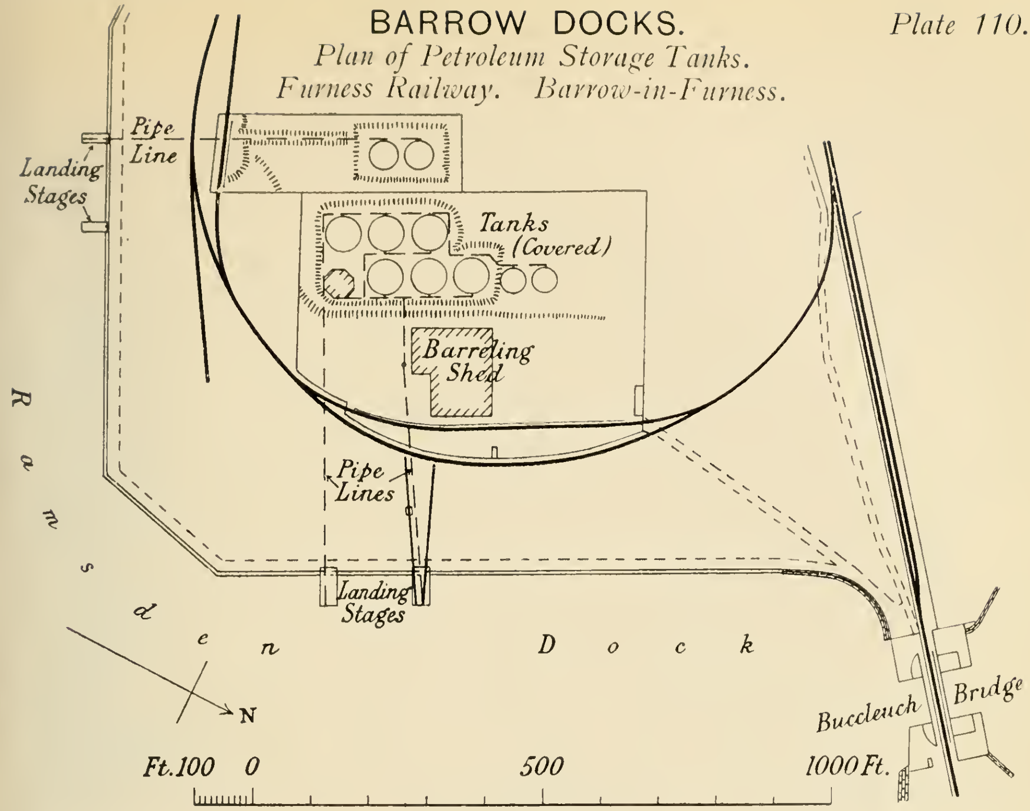
100-ft. Lock, 20 April, 1901. After lowering the Cill 6 feet.



BARROW DOCKS.

Plan of Petroleum Storage Tanks.

Furness Railway. Barrow-in-Furness.

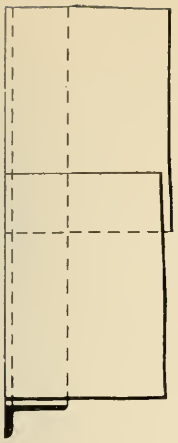


Petroleum Steamer.

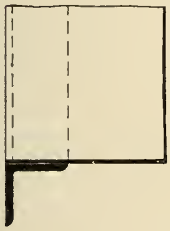
View of Tanks from Steamer.

Petroleum Tanks.

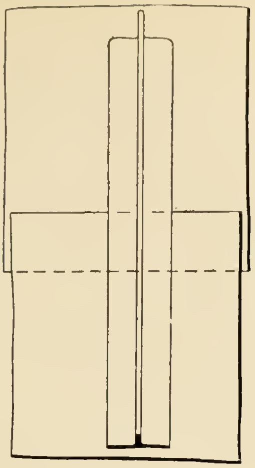
Half Sectional Elevation and Details.



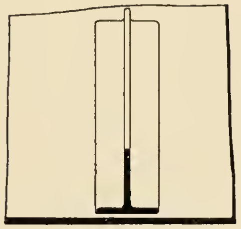
Detail at b.



Detail at a.

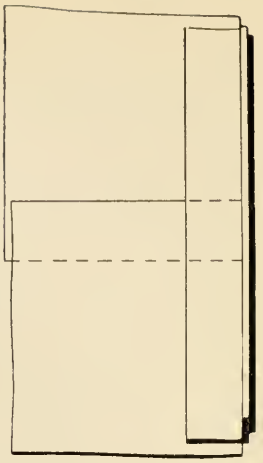


Detail at d.

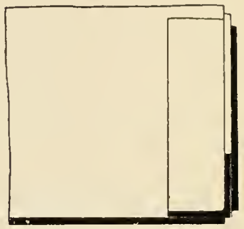


Section on cc.

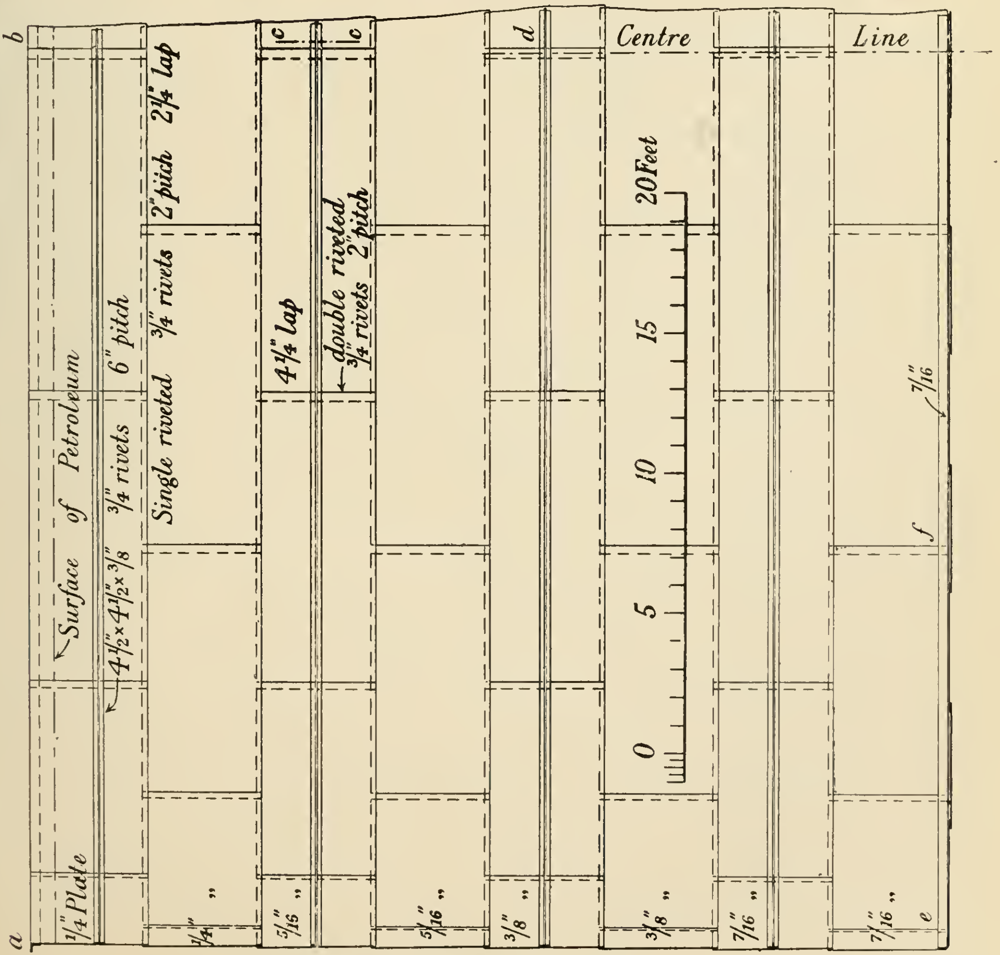
Scale for Details



Detail at f.

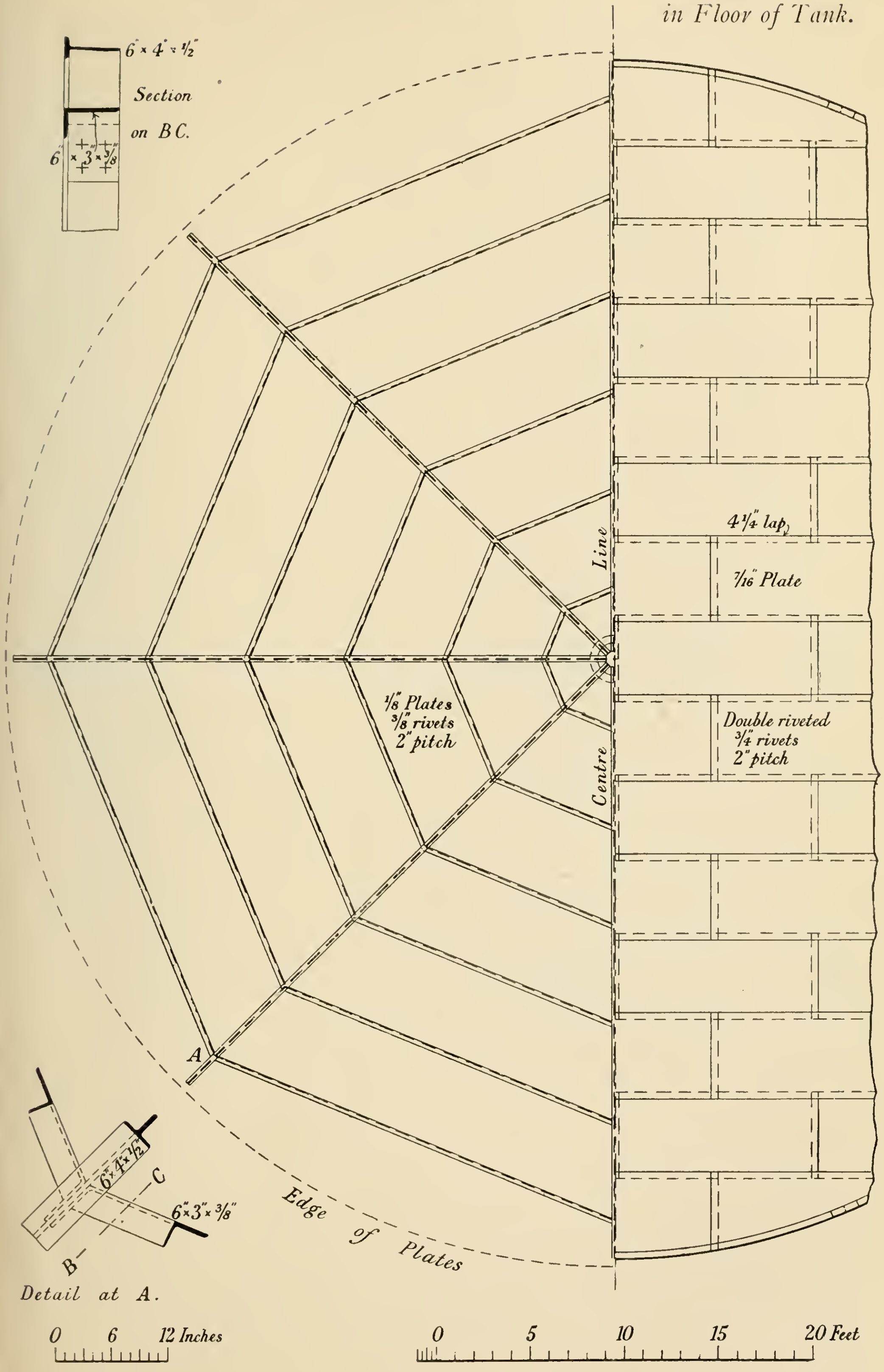


Detail at e.



BARROW DOCKS.

Petroleum Tanks.



Half Plan of Roof Framing.

Part Plan of Plates in Floor of Tank.

Plate 113.

Petroleum Tanks.

Elevation of Rib of Roof
and Details.

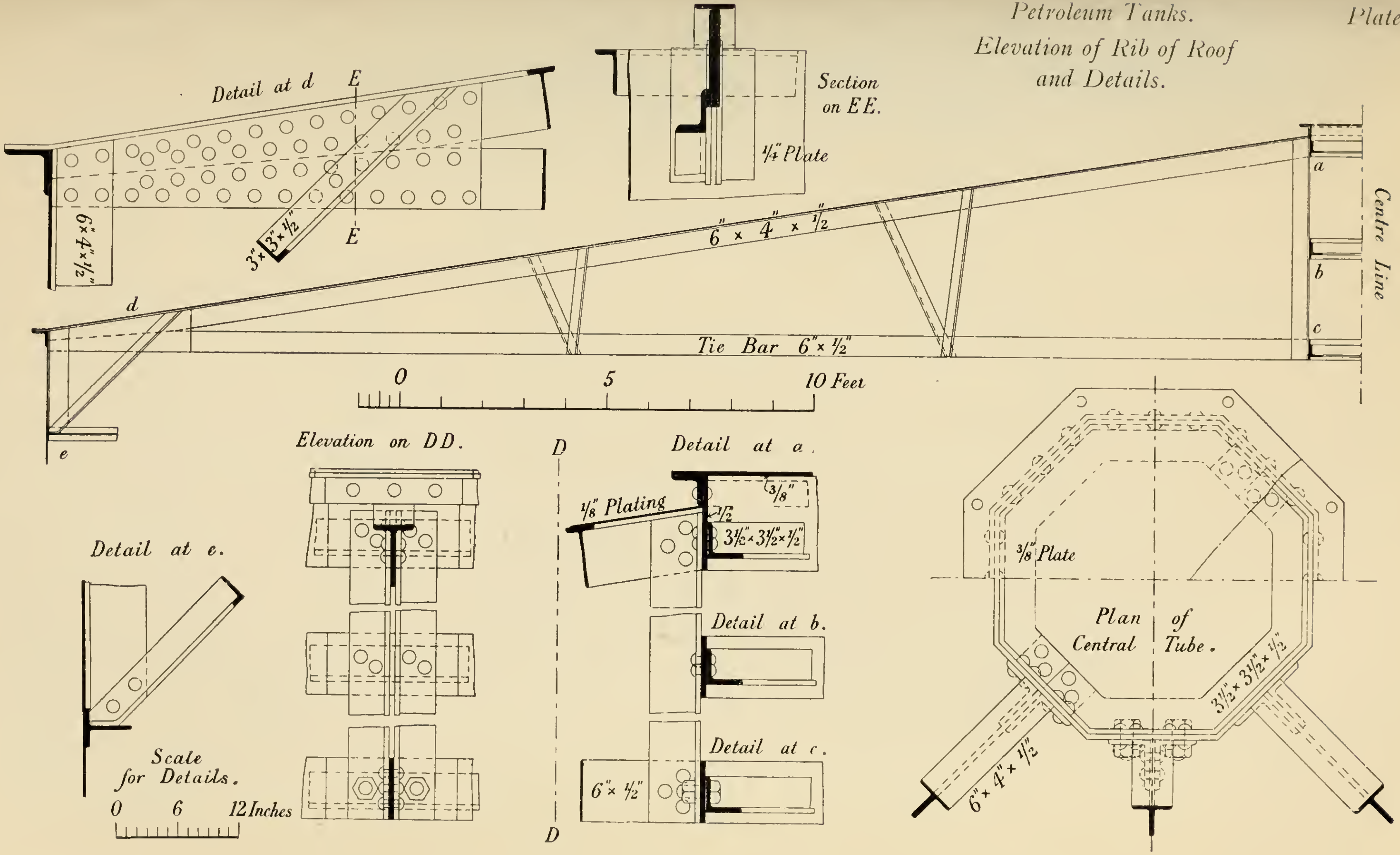


Plate 114.

One of the Boilers of Twin Screw Steamer "Ortona."

The thicknesses in block type are those calculated to conform to the Admiralty test pressure for a boiler of the same diameter.

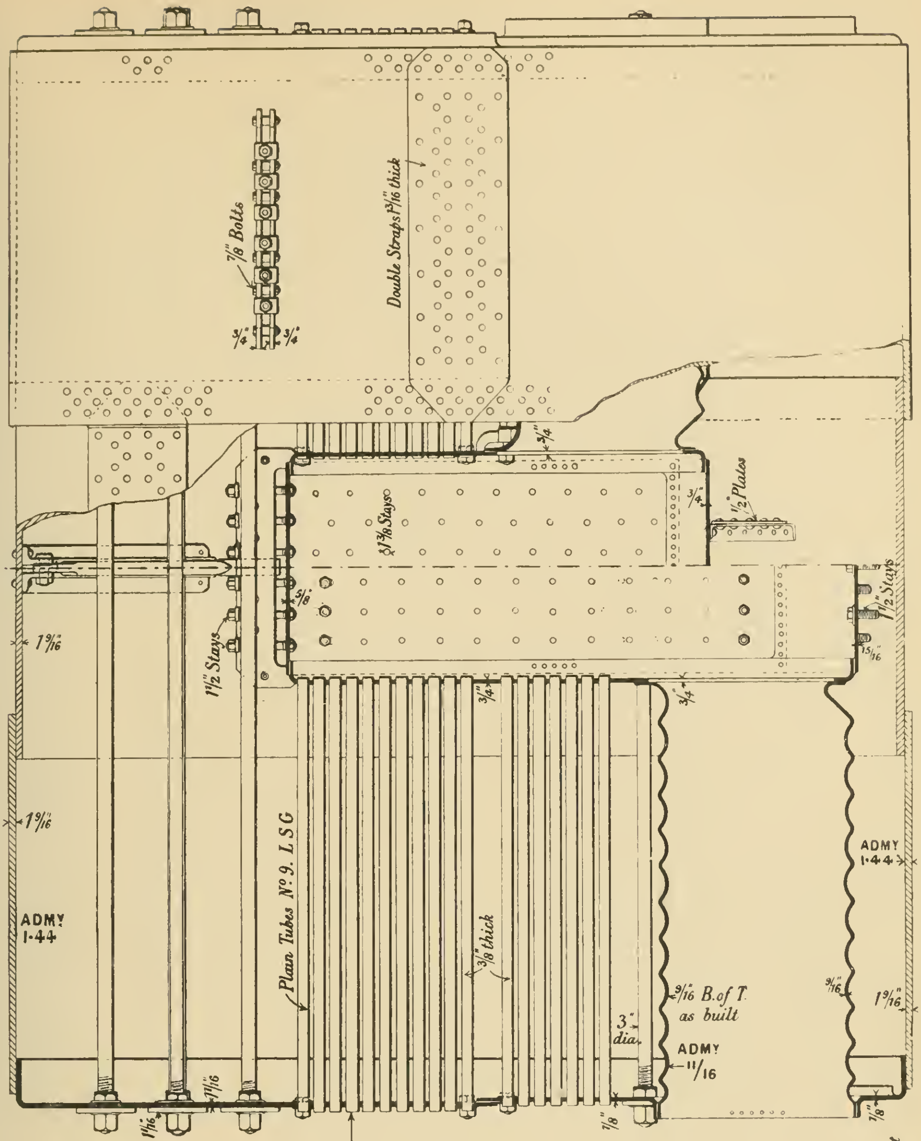


Fig. 3.

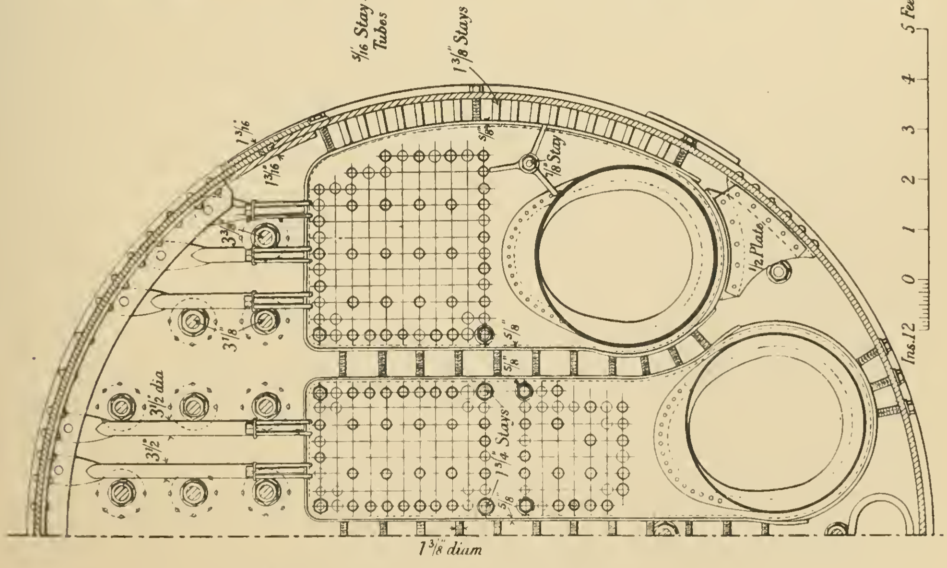


Fig. 2.

Mechanical Engineers 1901.

Two Engines of approximately 3,000 H.P. compared.

Fig. 24. *Torpedo Boat Destroyer Engines, 3,000 I.H.P.*

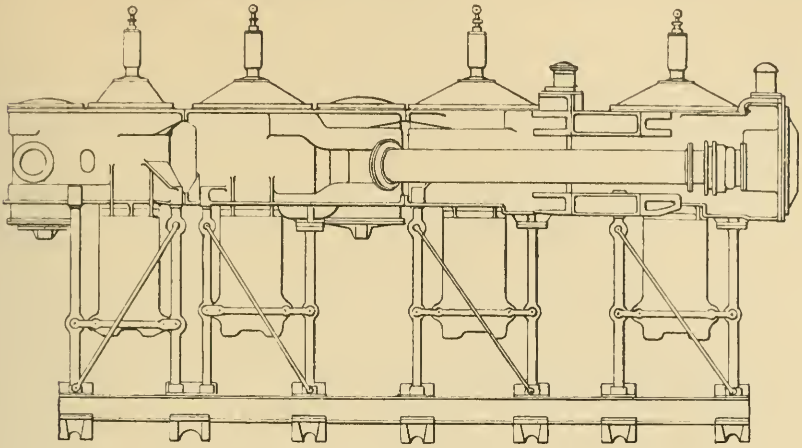
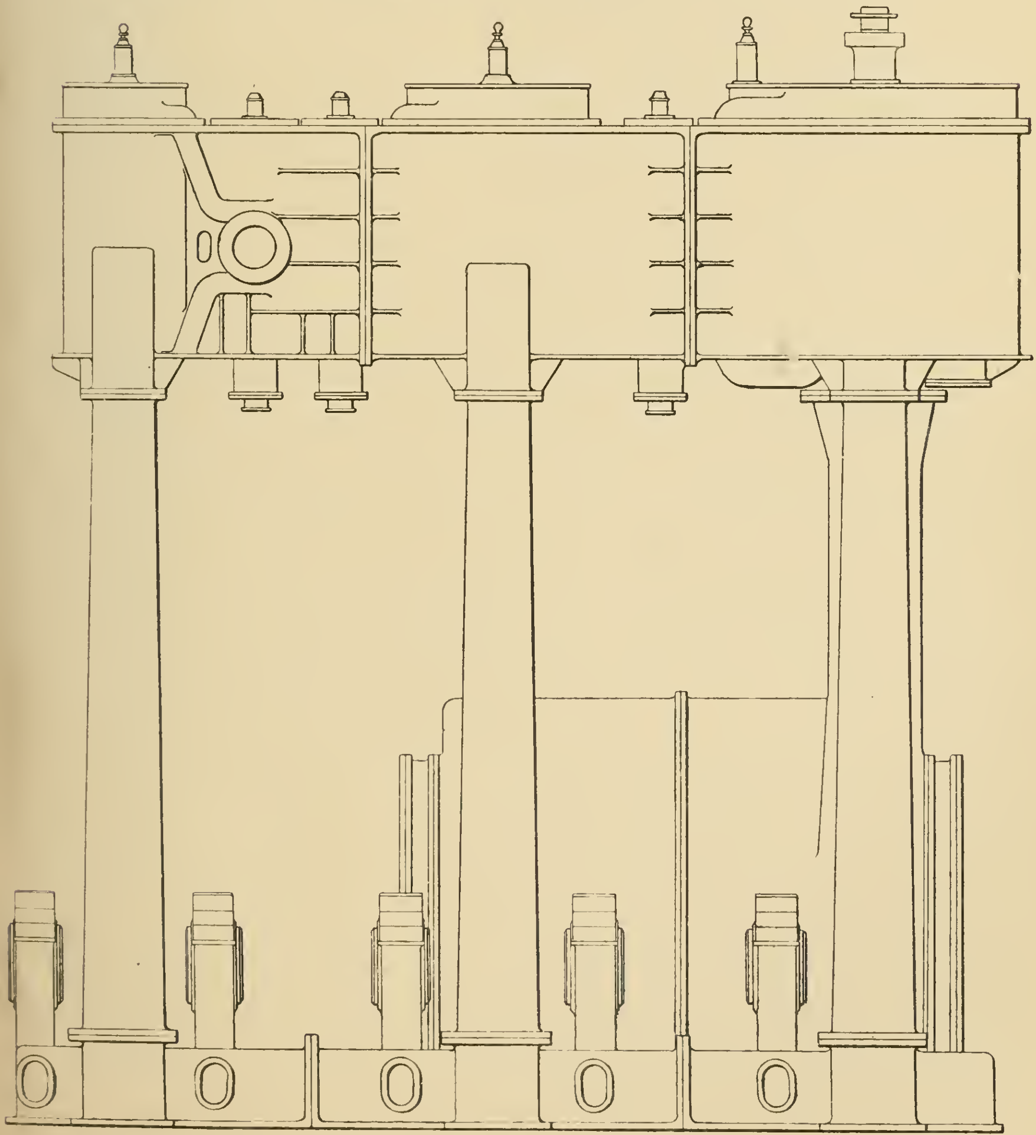


Fig. 25. *Merchant Vessel Engines, 3,000 I.H.P.*



(Both drawings are to same scale.)

Mechanical Engineers 1901.

Twin Screw Channel Steamer,
"Duke of Lancaster" (1894).

Fig. 26.

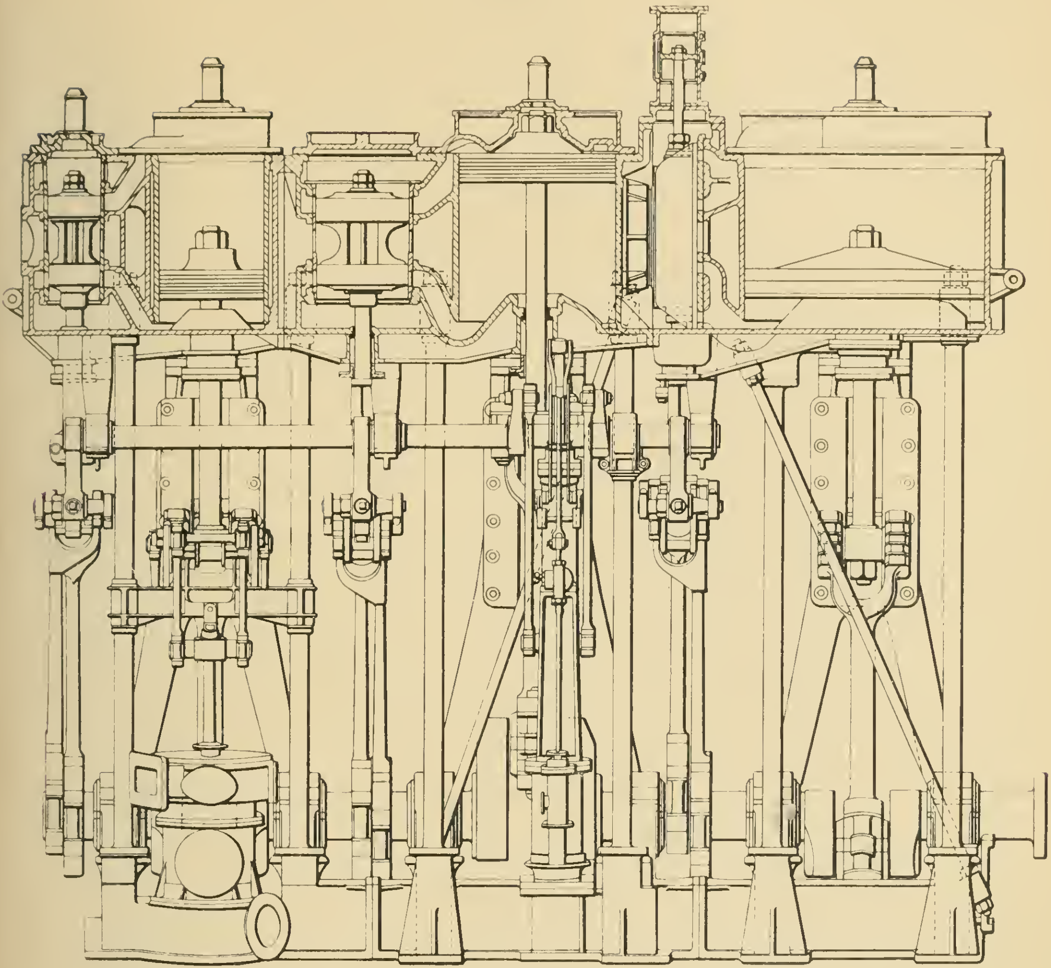
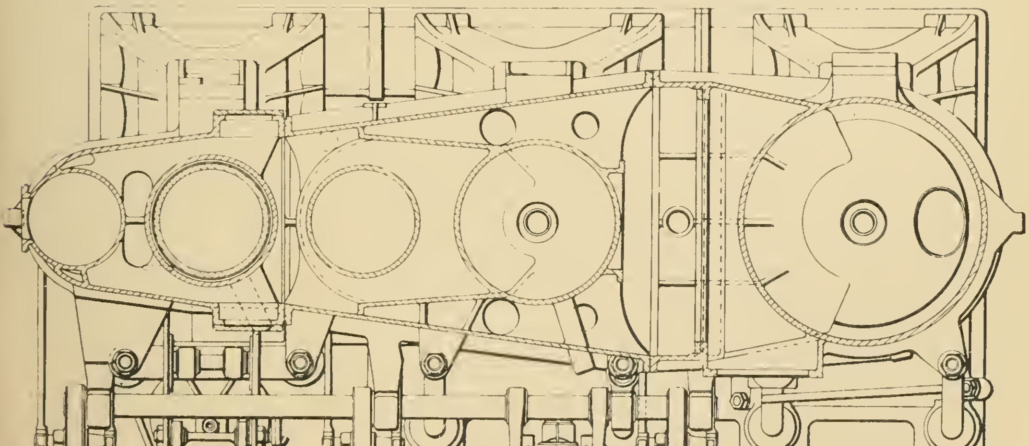
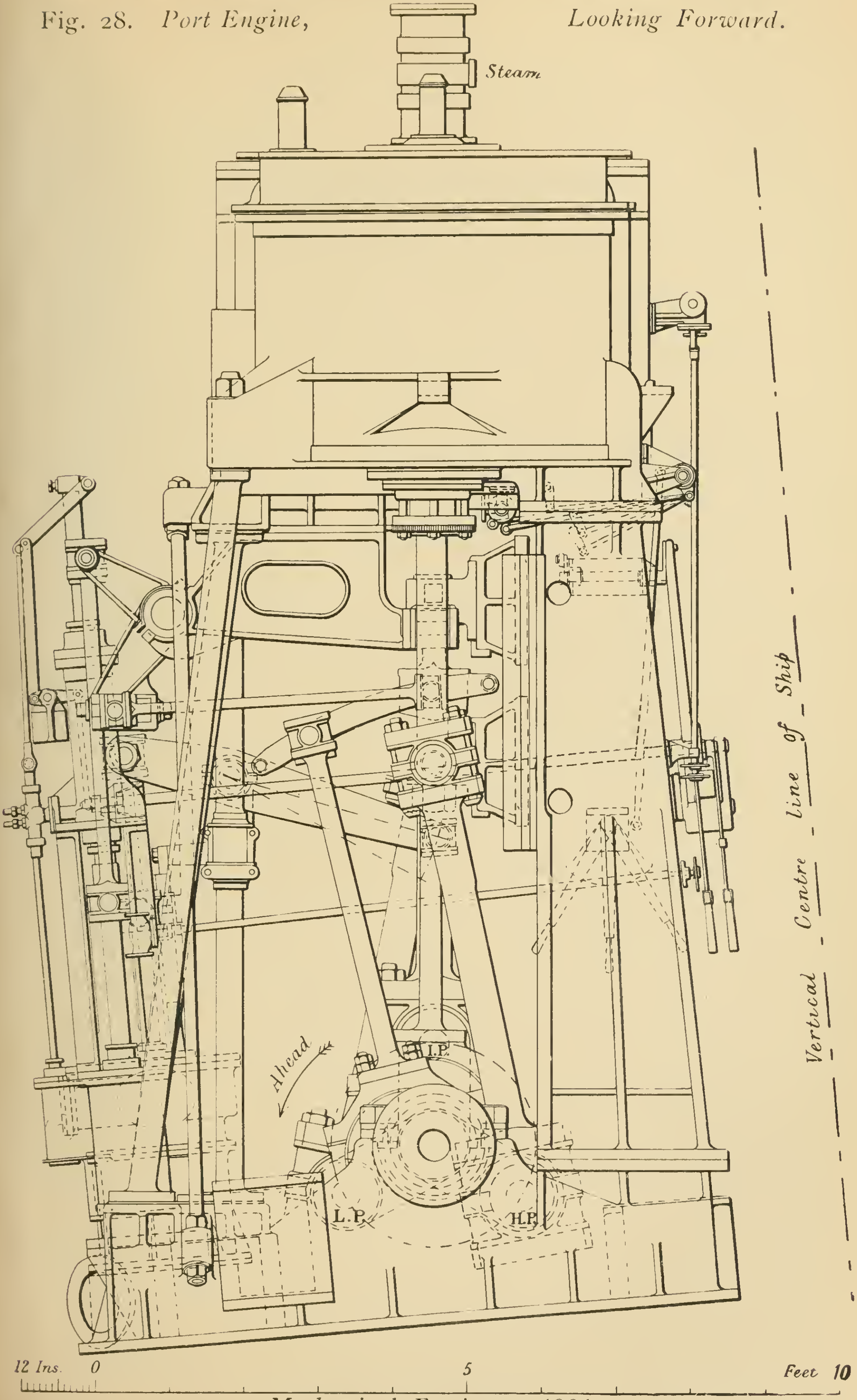


Fig. 27.



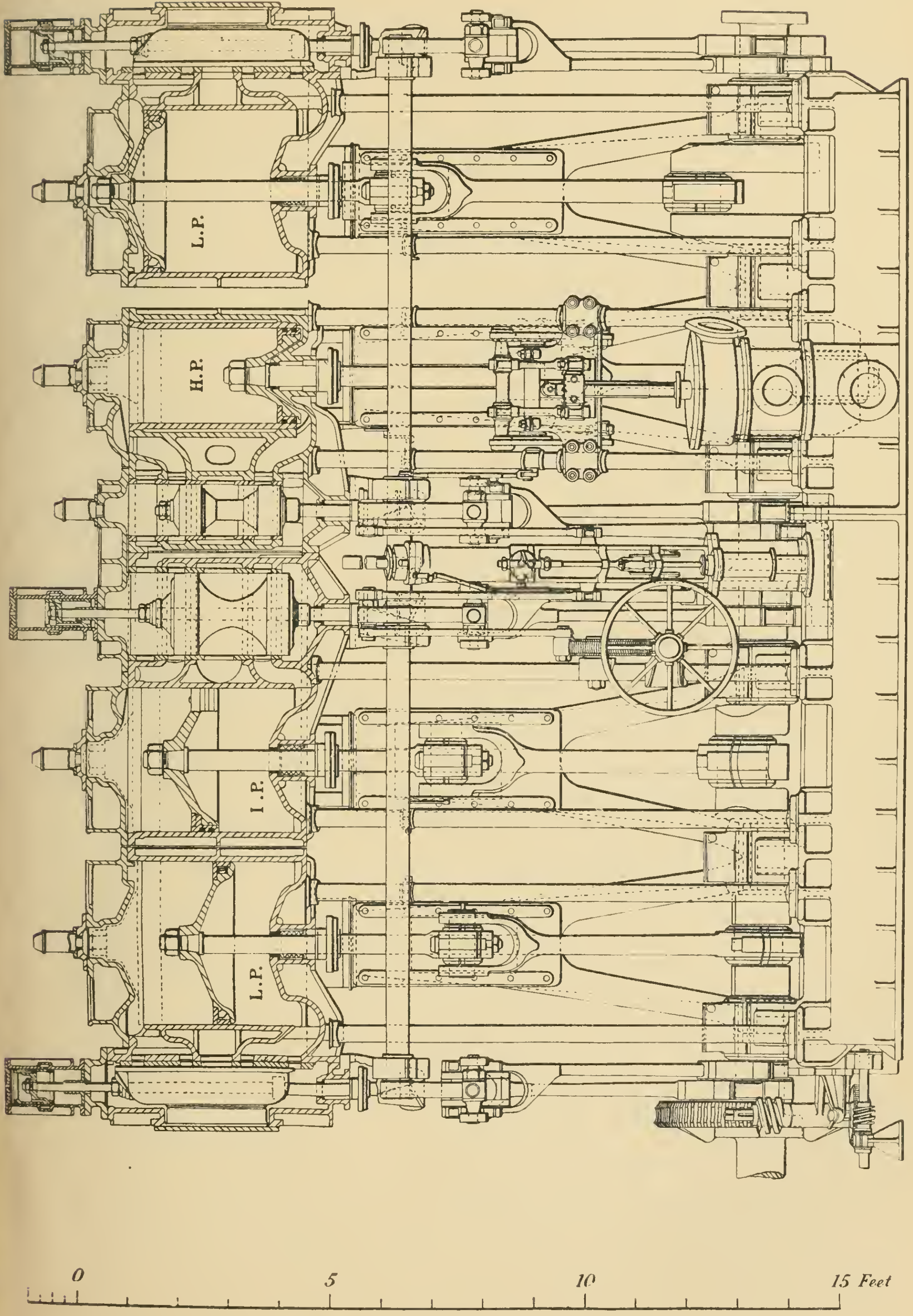
Twin Screw Channel Steamer, "Duke of Lancaster" (1894).

Fig. 28. *Port Engine, Looking Forward.*



Modern Twin Screw Channel Steamer,
"Duke of Cornwall."

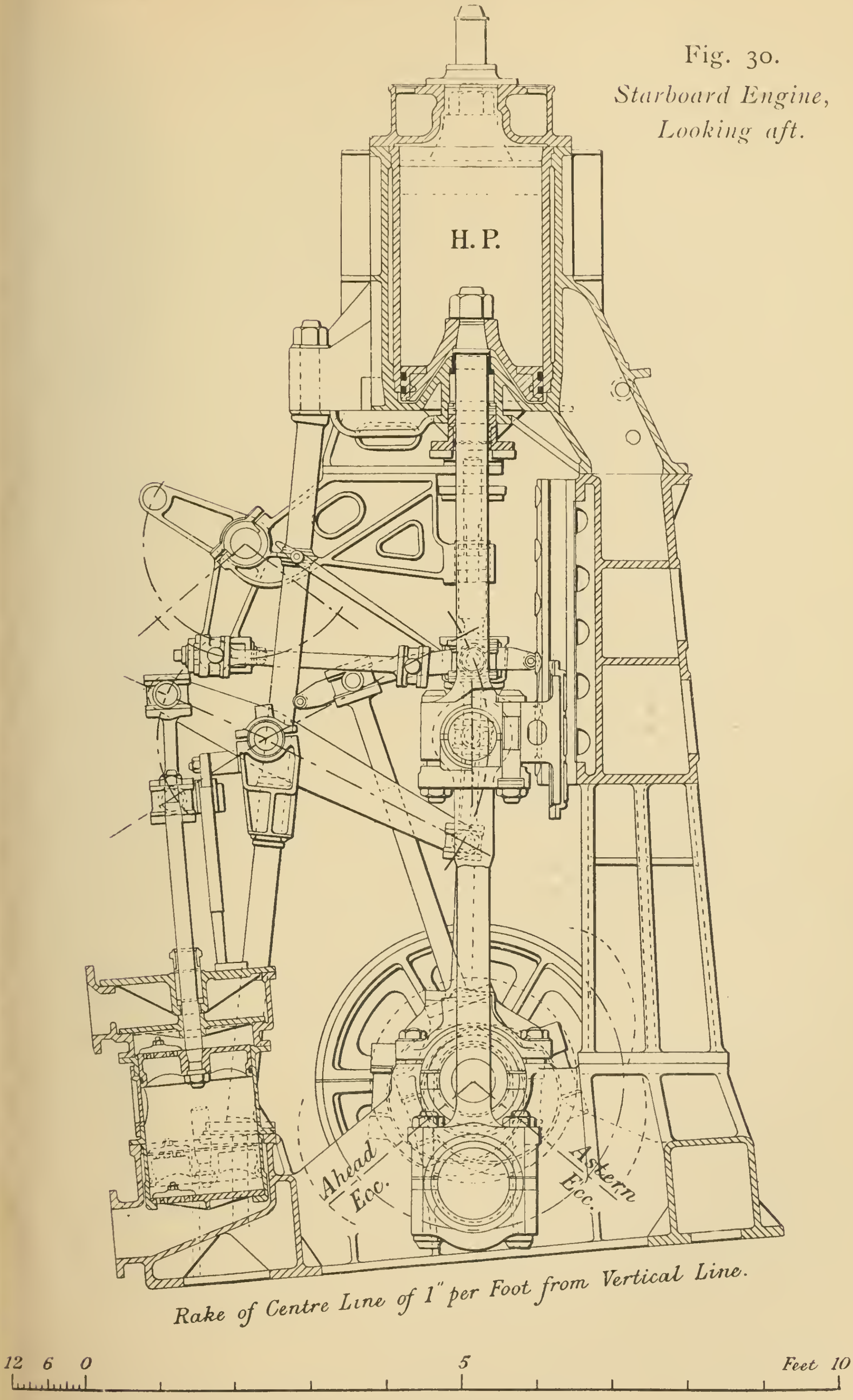
Fig. 29. *Starboard Engine.*



Modern Twin Screw Channel Steamer, "Duke of Cornwall."

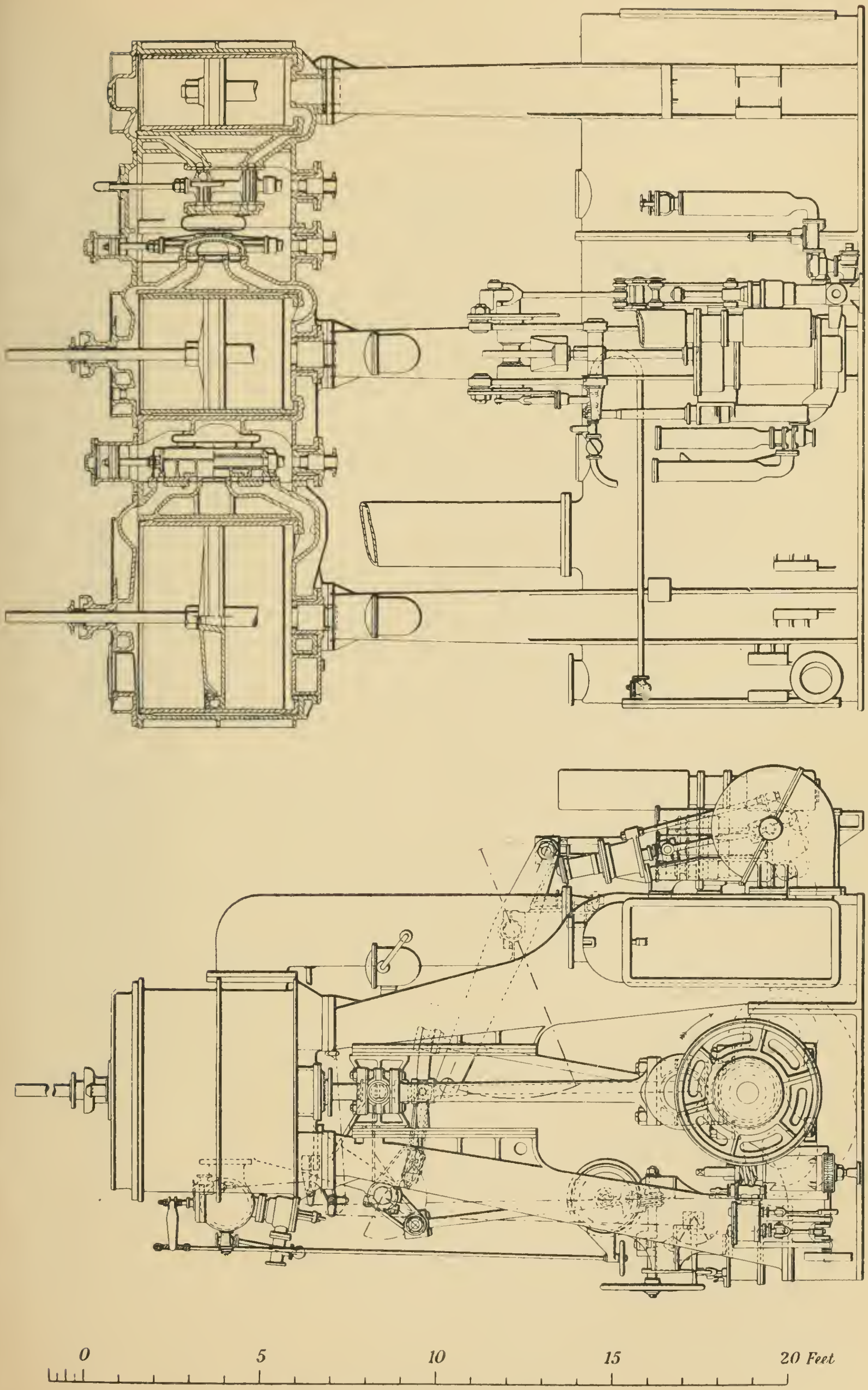
Fig. 30.

Starboard Engine,
Looking aft.



Mechanical Engineers 1901.

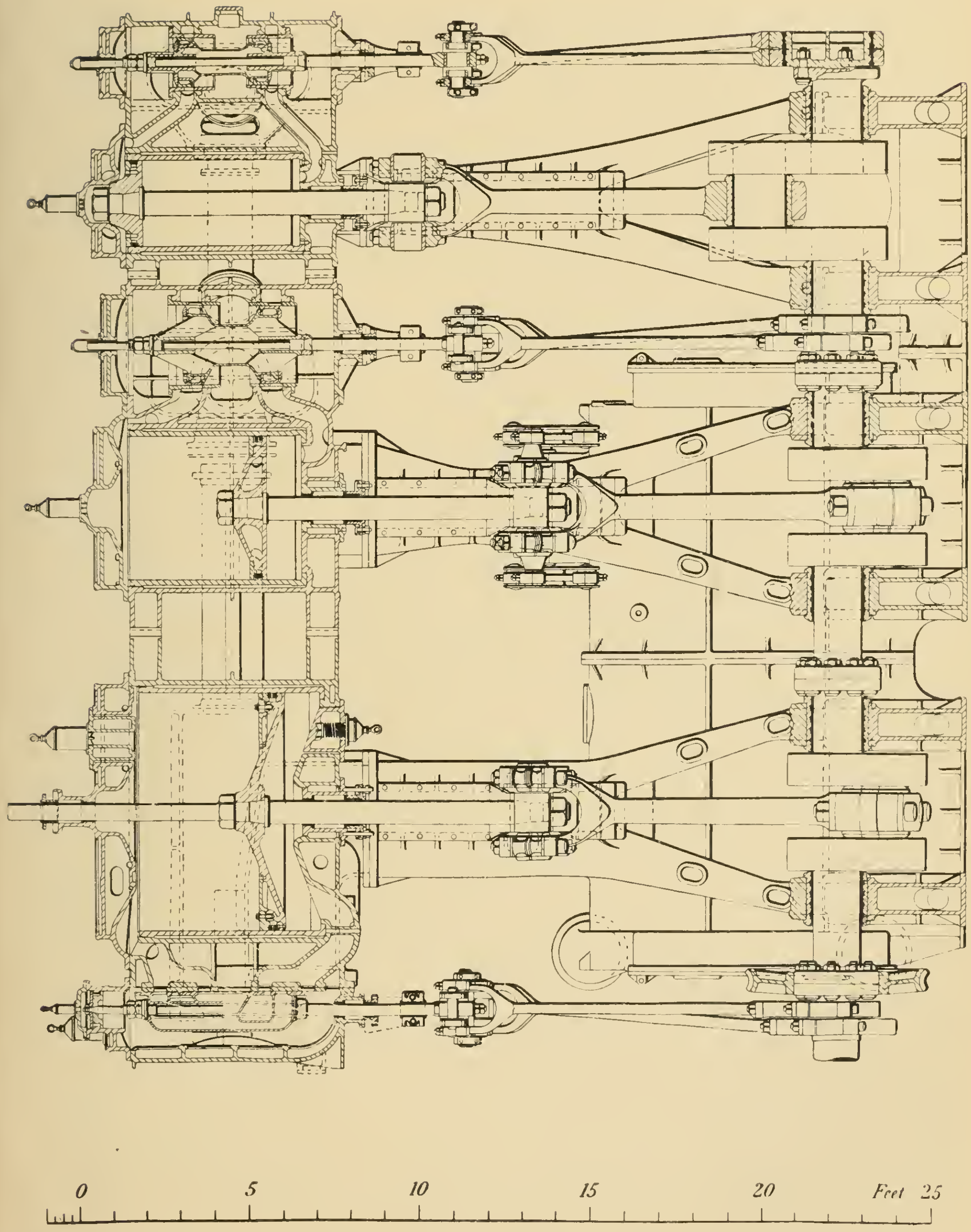
Fig. 31. *1st Class Cargo Steamer,*
"Bornu and Sokoto" (Modern).



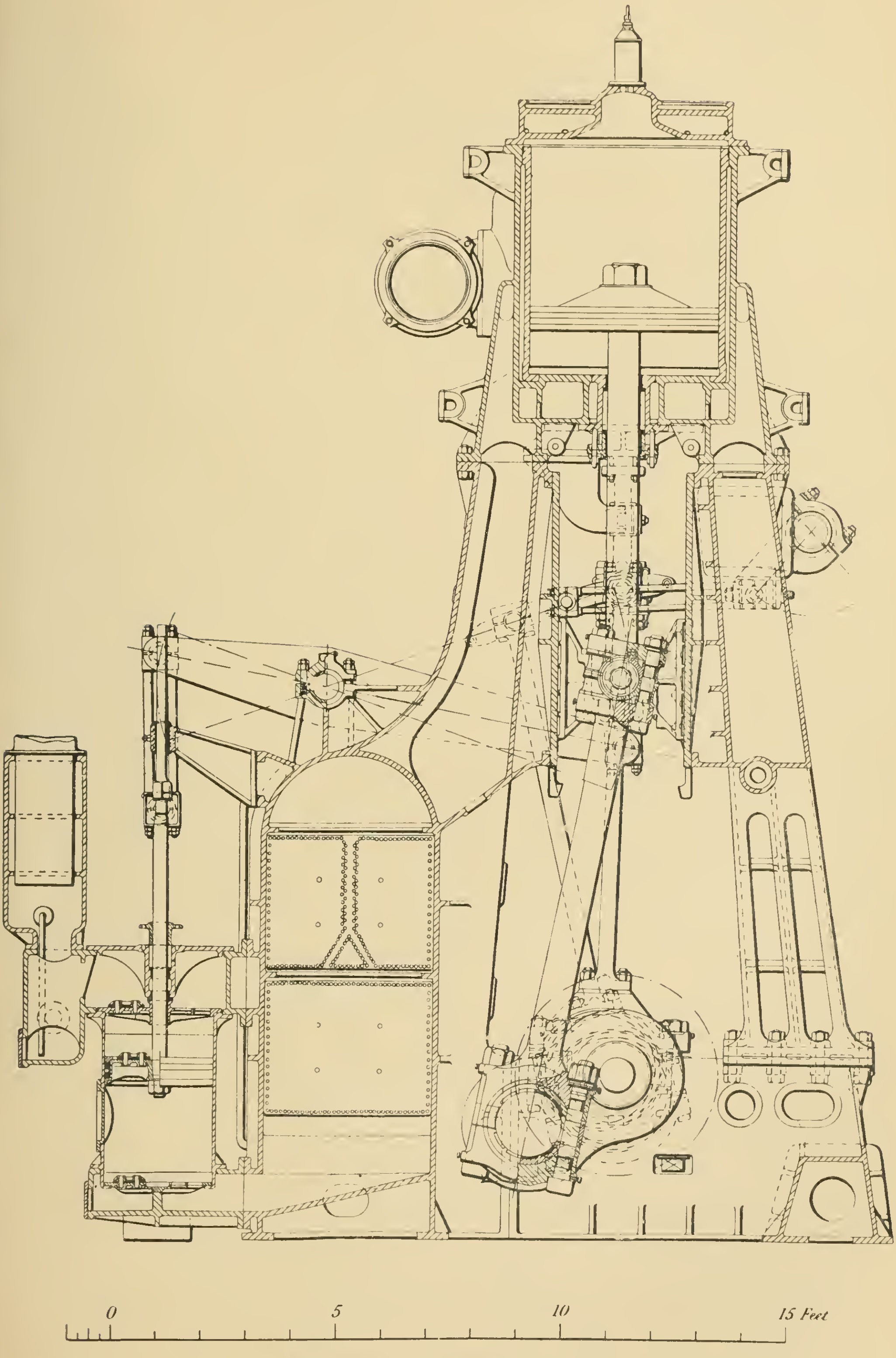
Twin Screw Steamer,

"Ortona" (Pacific Liner).

Fig. 32. *Port Engine.*

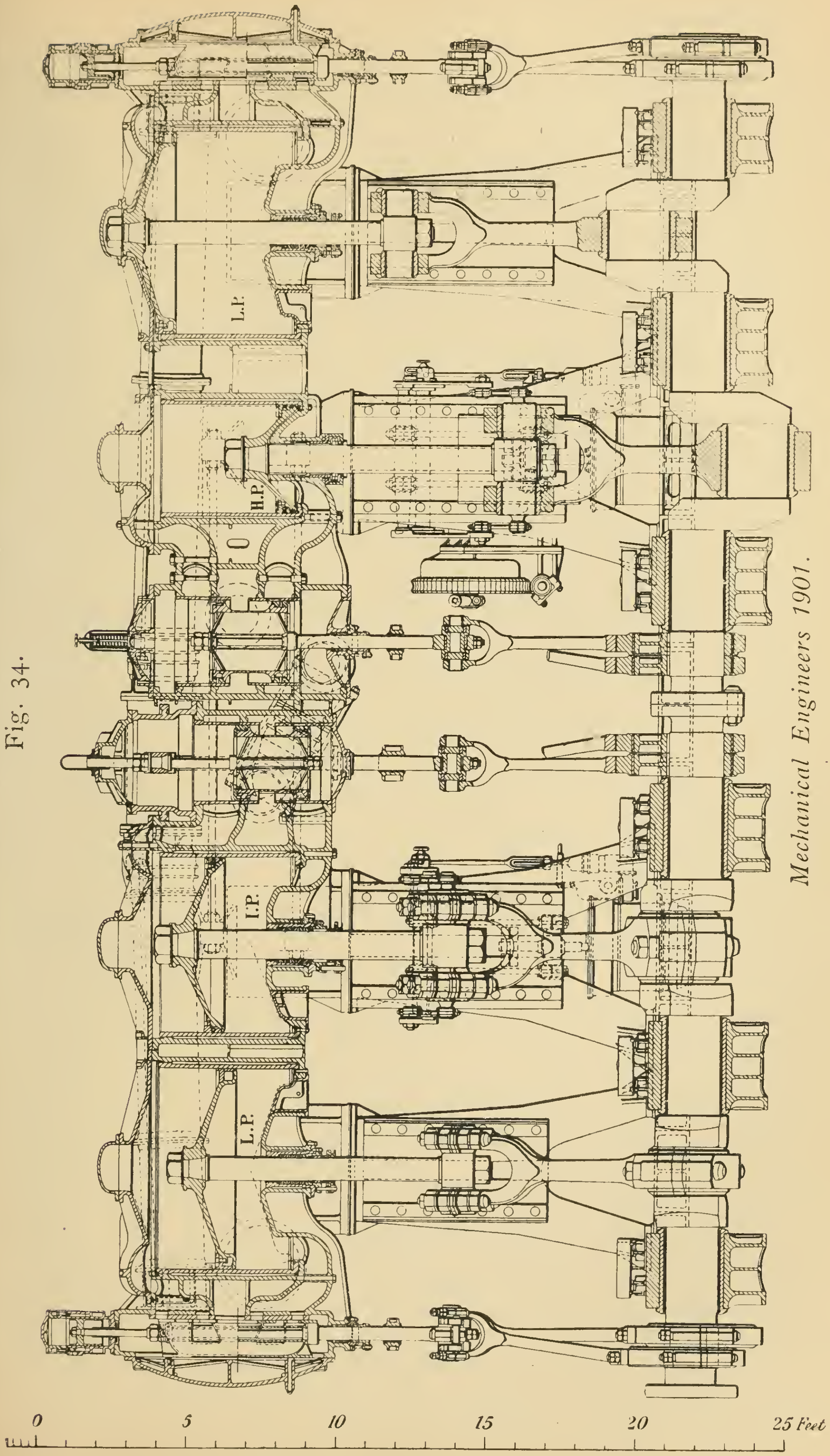


Twin Screw Steamer,
"Ortona" (Pacific Liner).
Fig. 33. *Port Engine.*



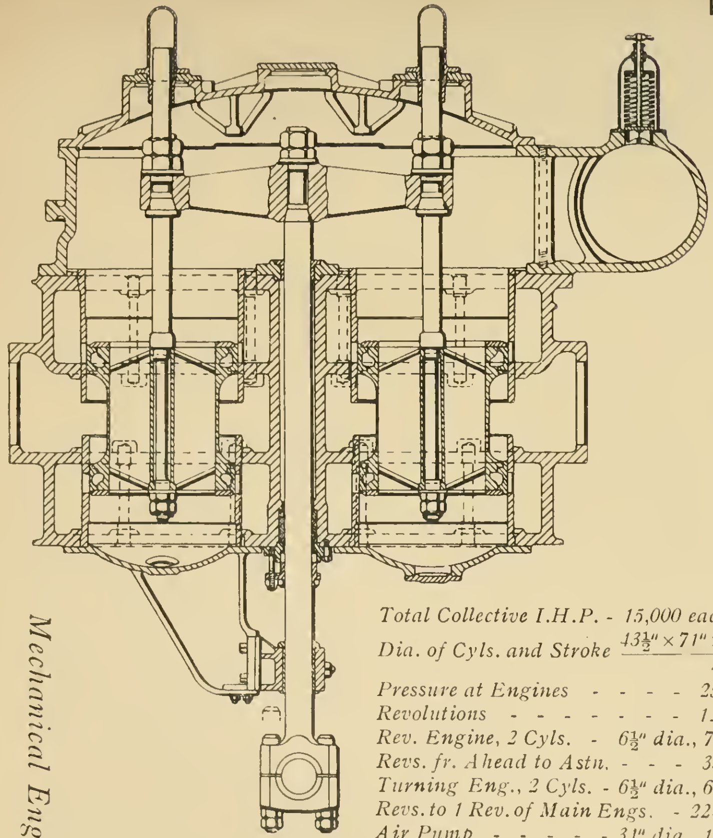
Armoured Cruiser, H.M.S. "King Alfred."

Fig. 34.



MARINE ENGINEERING.

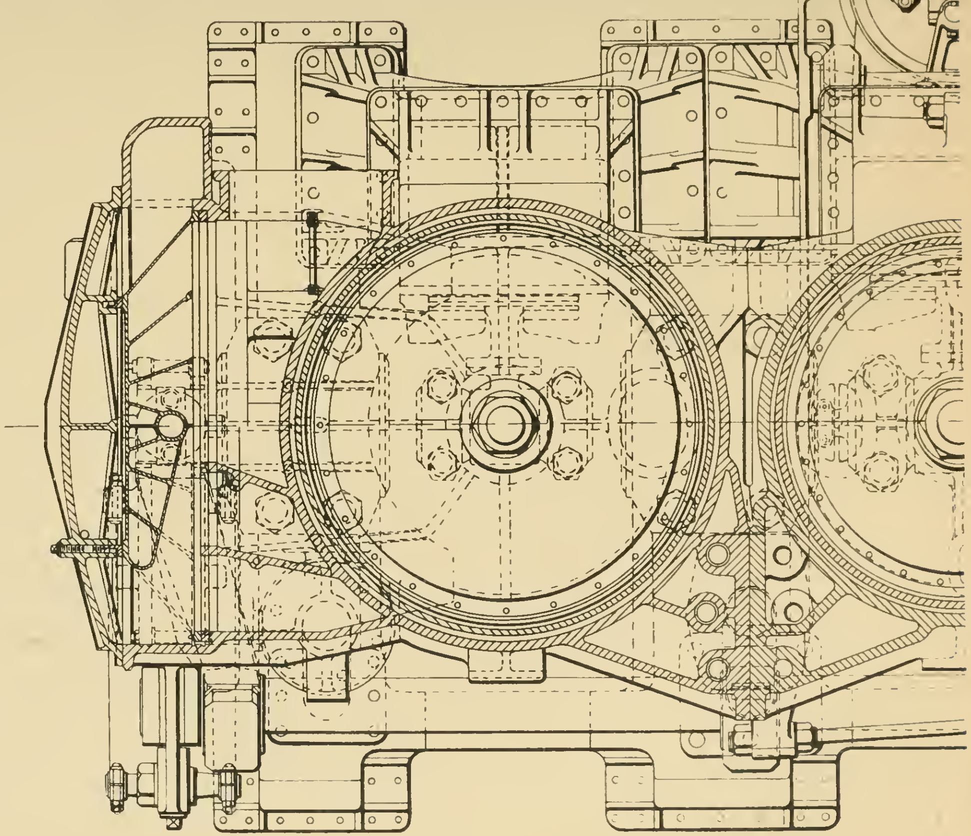
Armoured Cruiser,
H.M.S. "King Alfred."

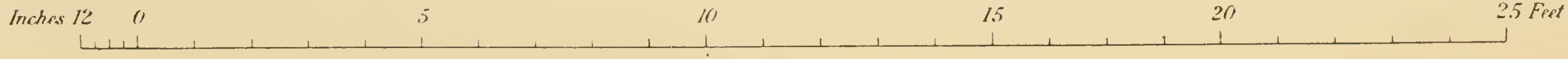


Total Collective I.H.P. - 15,000 each Engine.
Dia. of Cyls. and Stroke $\dfrac{43\frac{1}{2}'' \times 71'' \times 81\frac{1}{2}'' \times 81\frac{1}{2}''}{48}$
Pressure at Engines - - - - 250
Revolutions - - - - - - - - 120
Rev. Engine, 2 Cyls. - 6½″ dia., 7″ stroke.
Revs. fr. Ahead to Astn. - - - 33
Turning Eng., 2 Cyls. - 6½″ dia., 6″ stroke
Revs. to 1 Rev. of Main Engs. - 2240
Air Pump - - - - - 31″ dia., 15½″ stroke.

Fig. 35.
Section through I.P. Casing,
Looking aft.

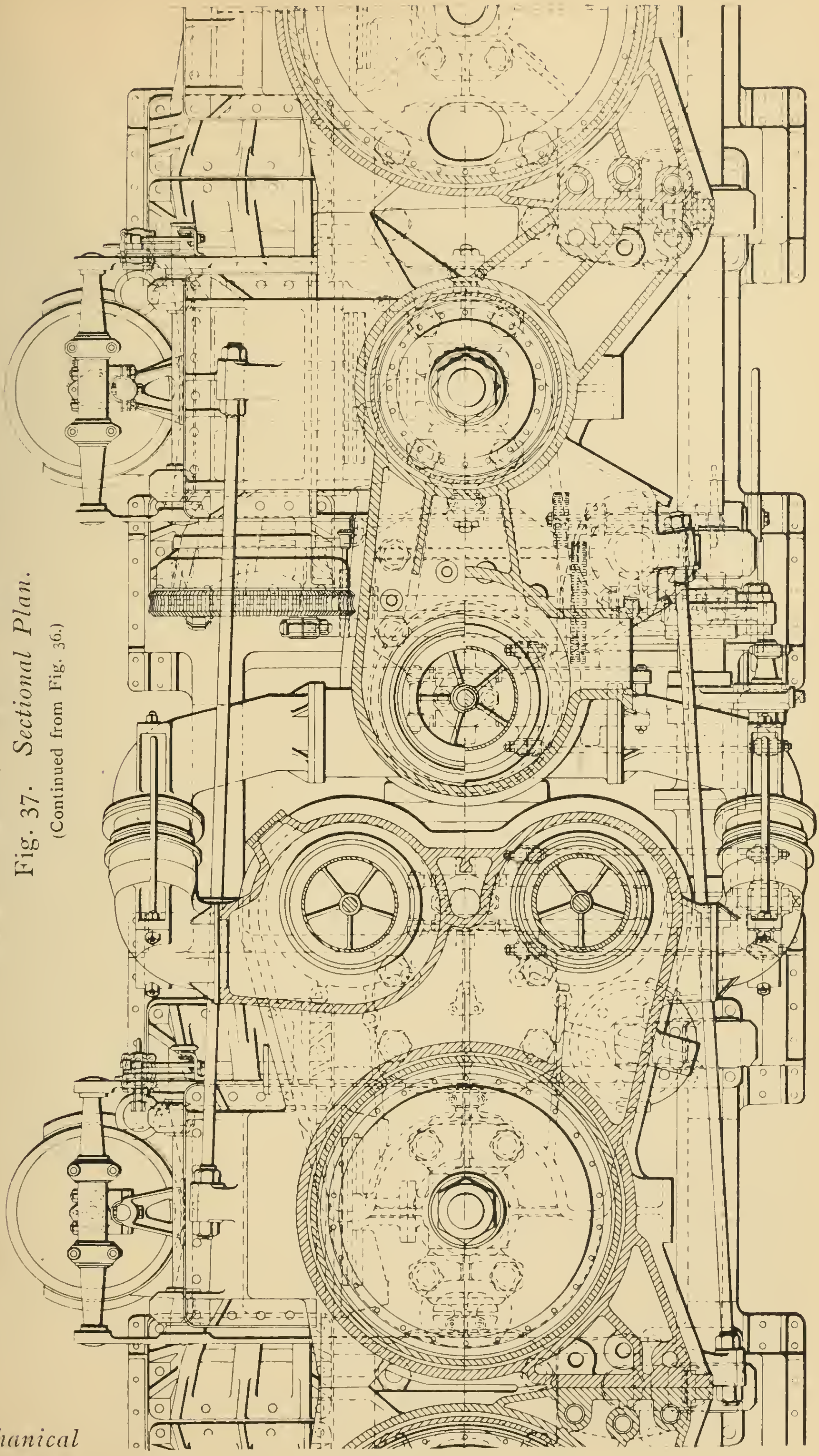
Fig. 36.
Sectional Plan.
(Continued on Fig. 37.)





CONTINUED ON PLATE 125.

OTHER HALF OF CYLINDER SIMILAR TO OTHER END, PLATE 124.



MARINE ENGINEERING.

Armoured Cruiser, H.M.S. "King Alfred."

Fig. 37. Sectional Plan.

(Continued from Fig. 36.)

CONTINUED FROM PLATE 124.

Armoured Cruiser,
H.M.S. "King Alfred."

Fig. 38.
Looking Aft.

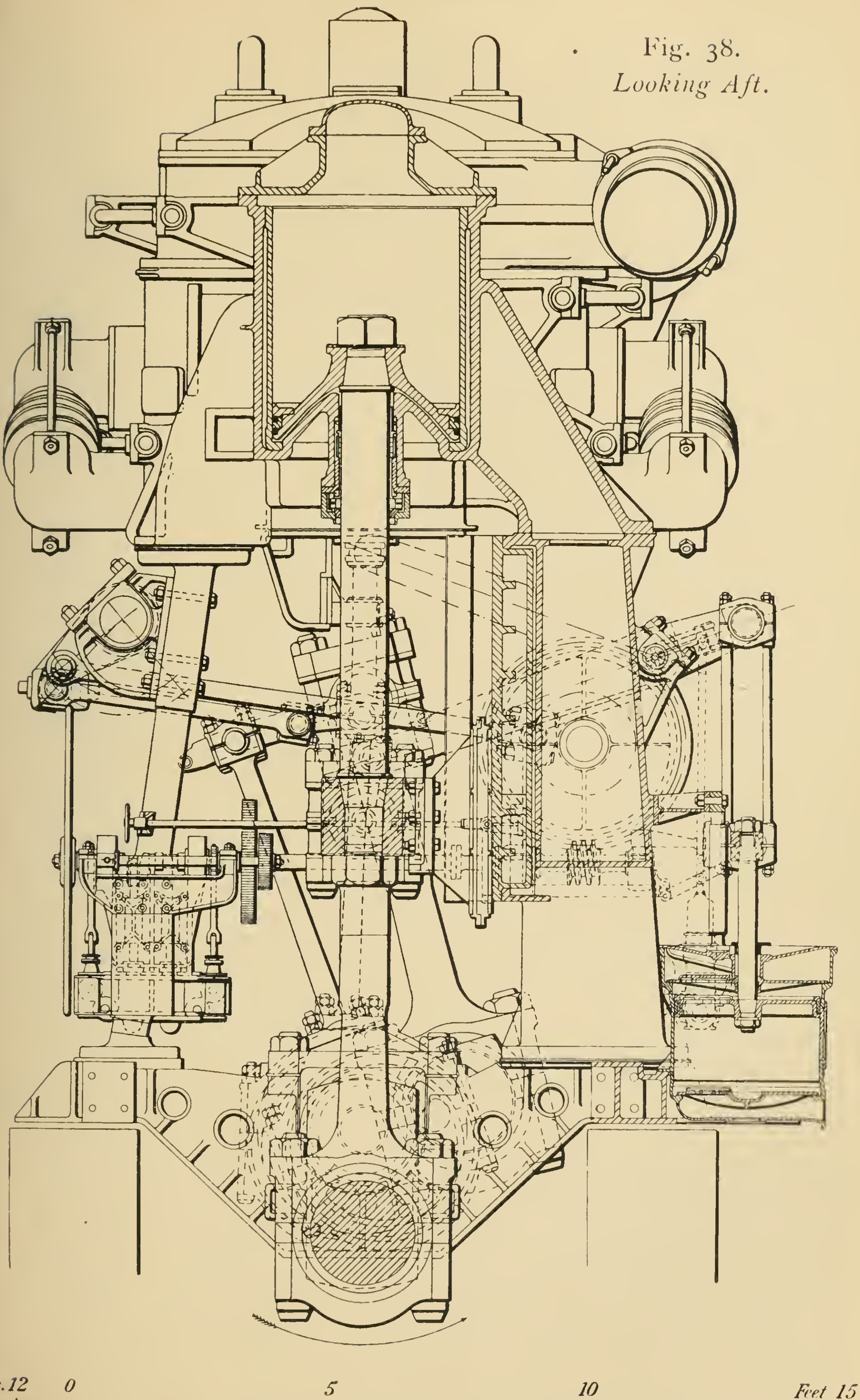
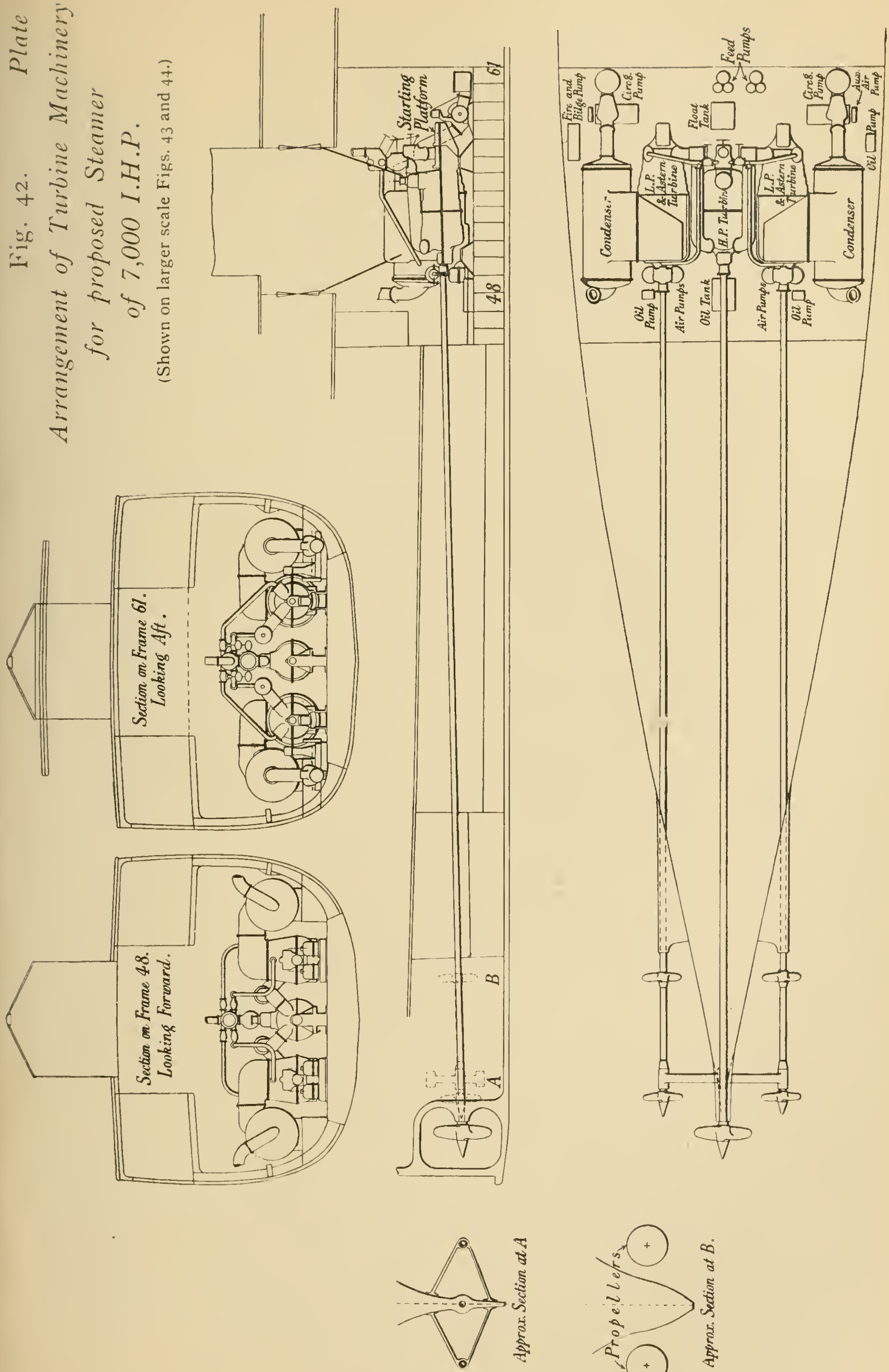


Fig. 42. Plate 127.

Arrangement of Turbine Machinery for proposed Steamer of 7,000 I.H.P.

(Shown on larger scale Figs. 43 and 44.)



Comparison between the Turbine (Fig. 42.) and reciprocating Engines of 7,000 H.P. for Channel service.

Fig. 43.

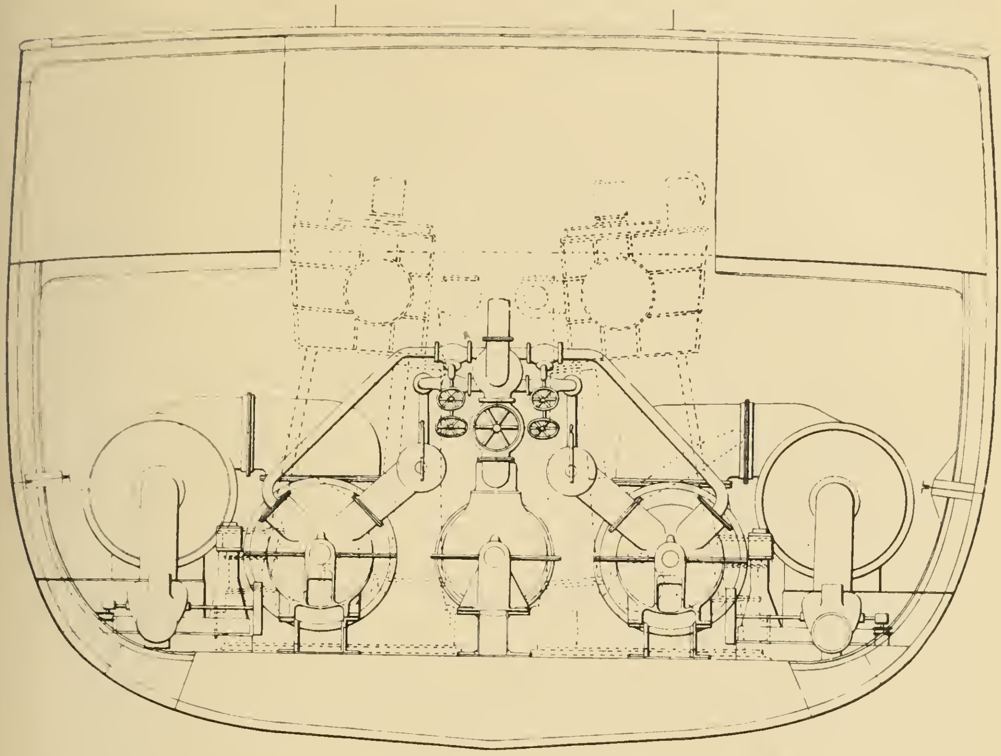
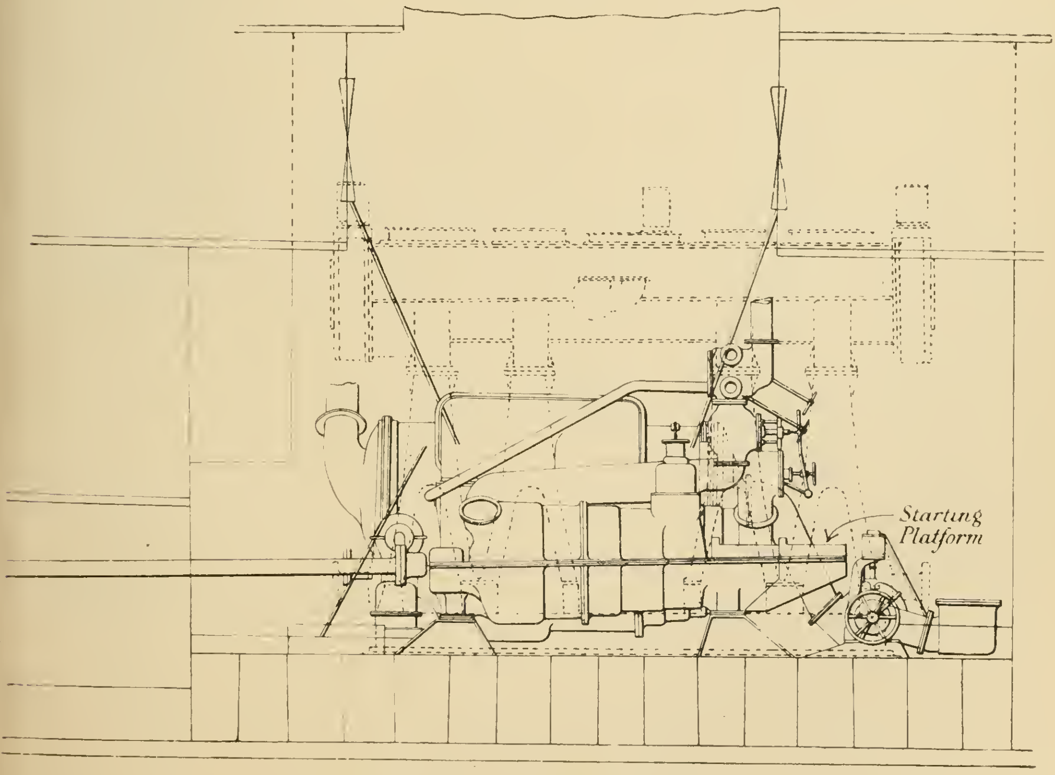


Fig. 44.



General Arrangement of Oil-Engine.

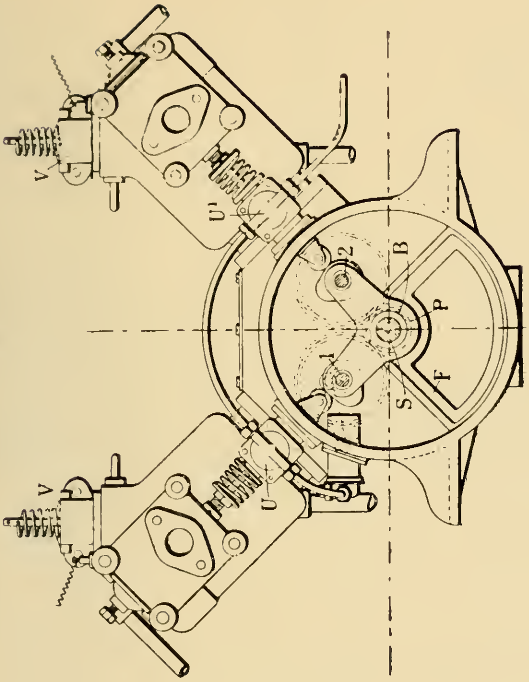


Fig. 2.

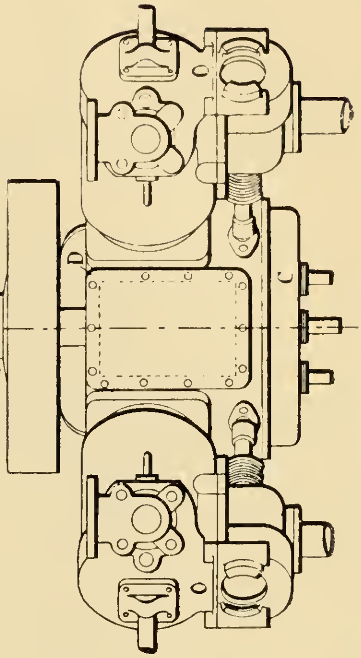


Fig. 3.

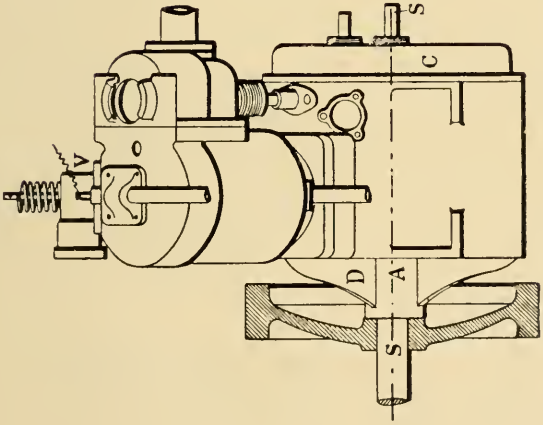


Fig. 1.

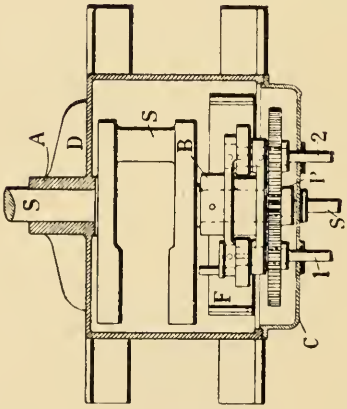


Fig. 4.

Adjustable Piston and Connecting Rod. Details of Engine. Exhaust Valve. Plate 130.

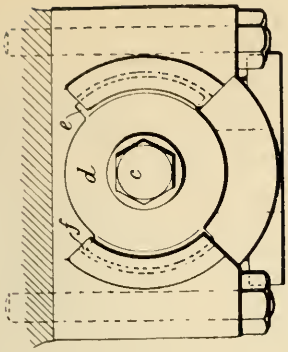
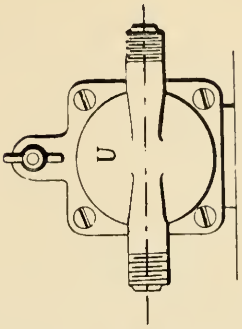


Fig. 10.



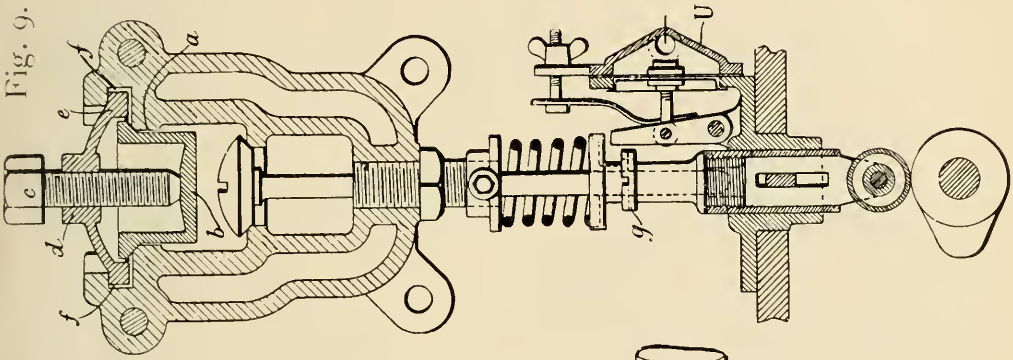


Fig. 9.

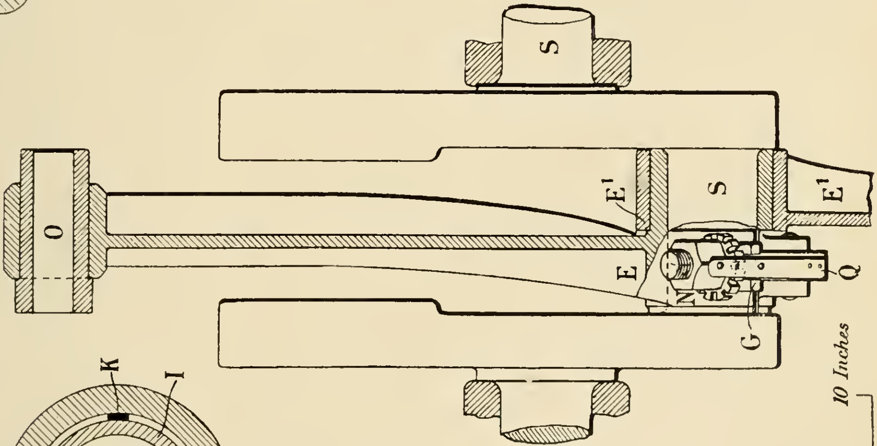


Fig. 7.

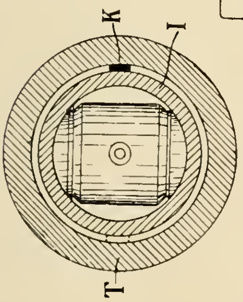


Fig. 6.

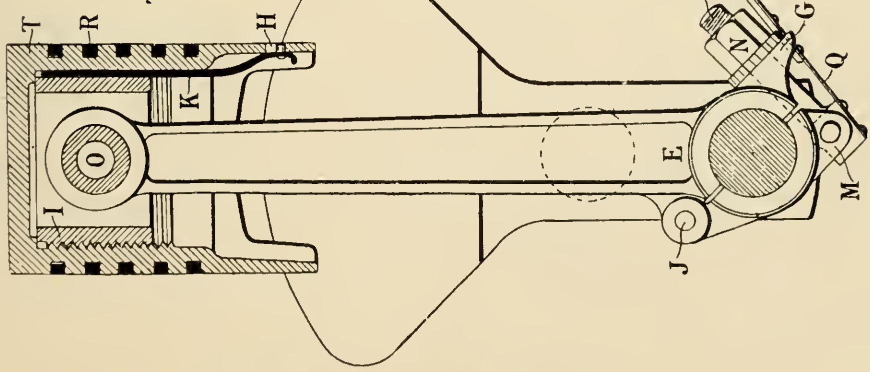


Fig. 5.

10 Inches

Pulsating Carburettor for 1½-inch Pipe.

Fig. 11.
Section at 1,1.

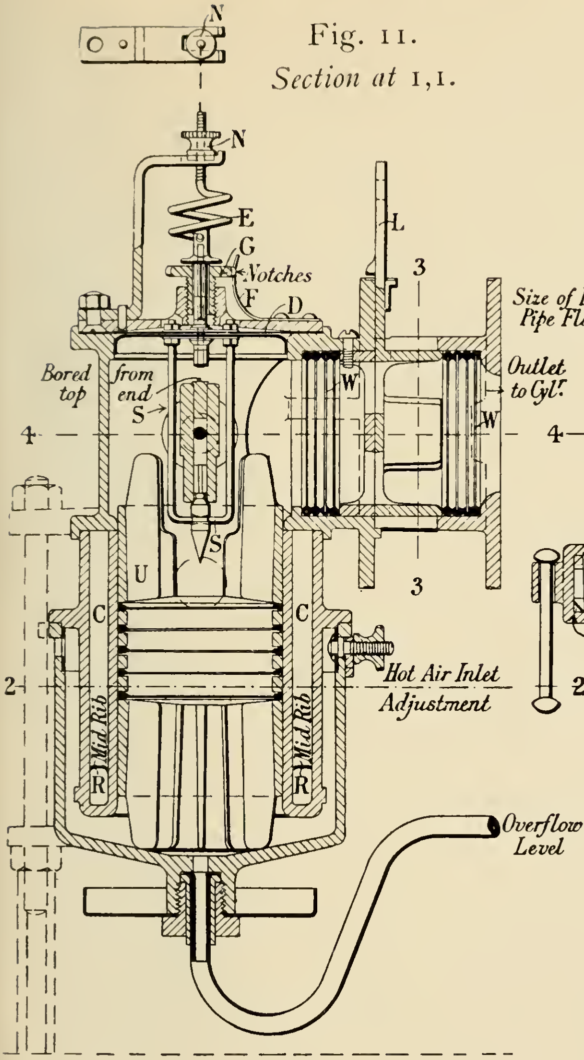


Fig. 12.
Side Elevation and Half Section at 3,3.

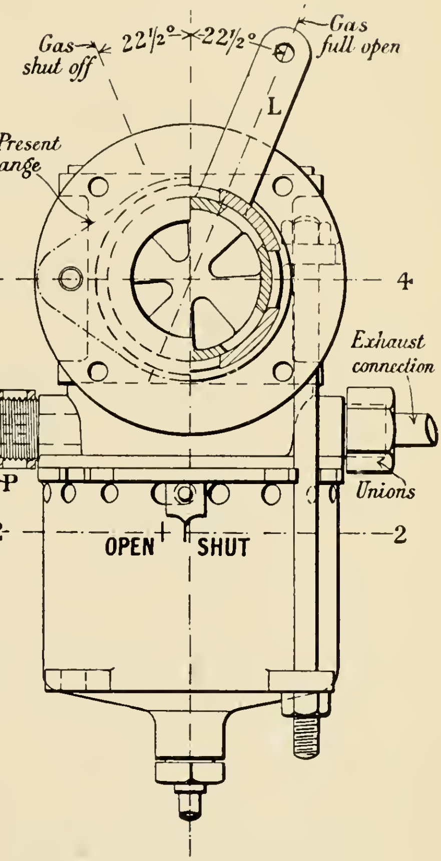


Fig. 13.
Section at 2,2.

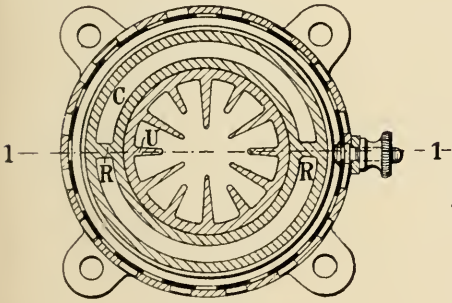
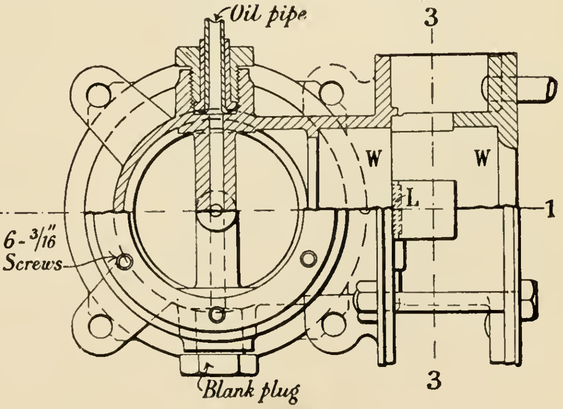
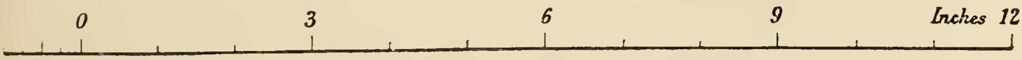
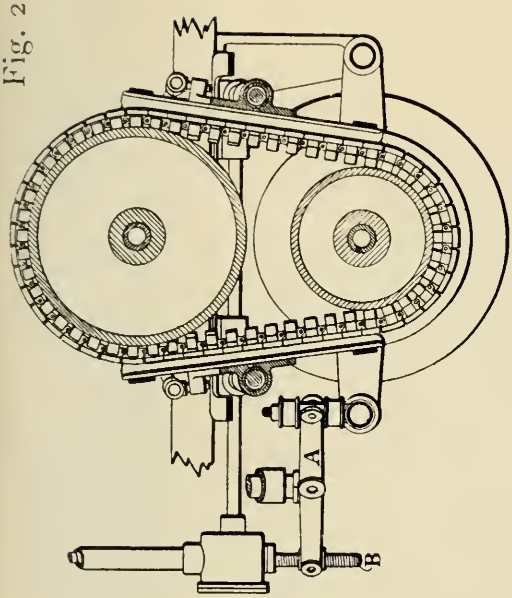


Fig. 14.
Half Section at 4,4 and Half Plan.







Variable-Speed Belt Drive
with Friction Wheel Reversing Gear.

Fig. 21.

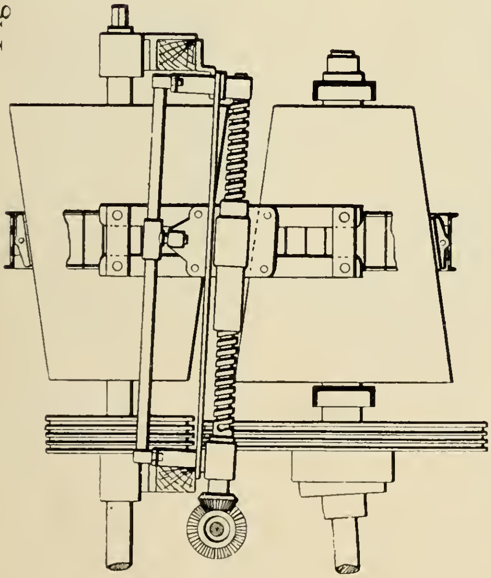


Fig. 22.

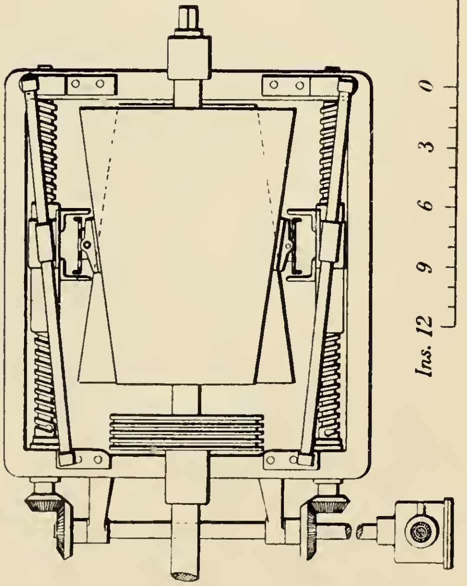


Fig. 25. *Experimental Petrol Car.*

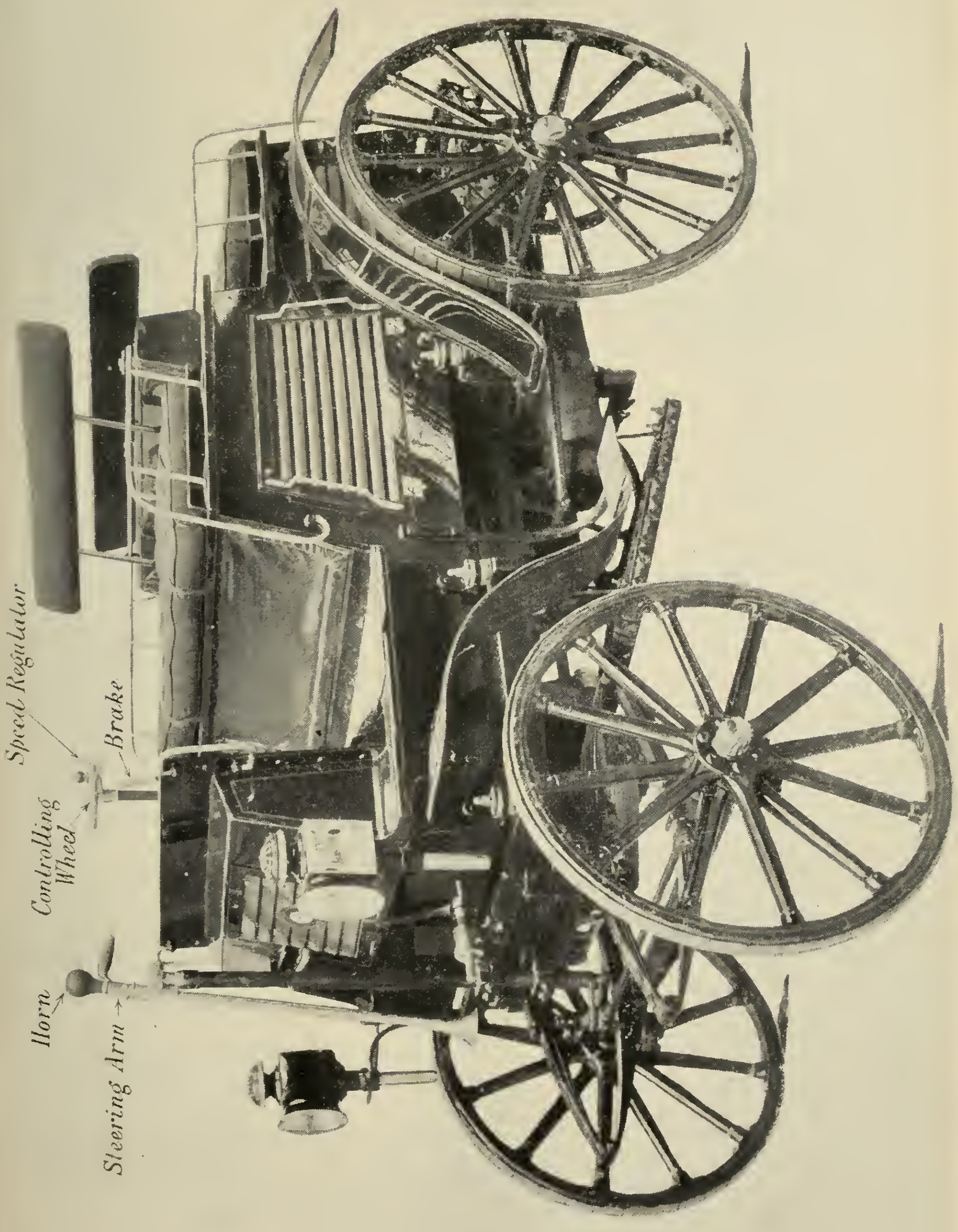


Fig. 1. *Bird's Eye View.*

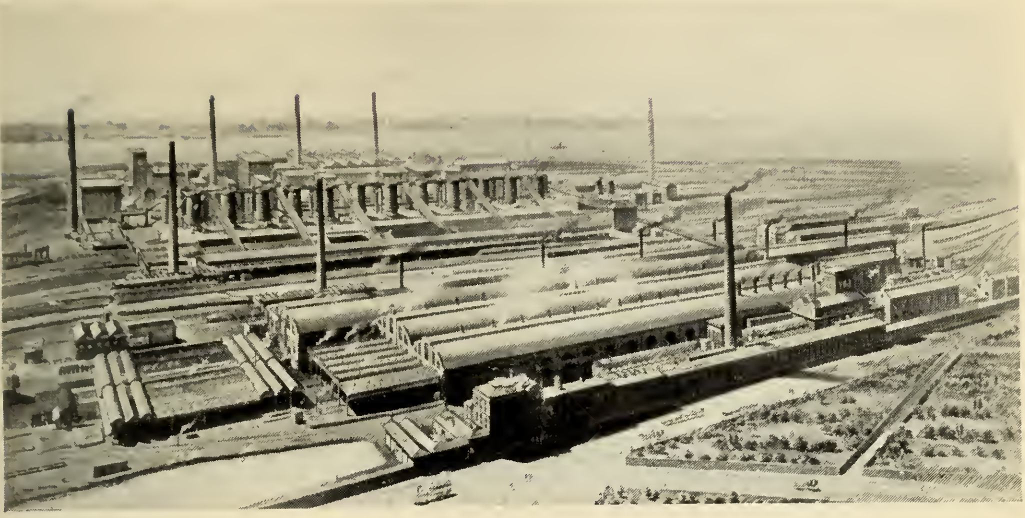
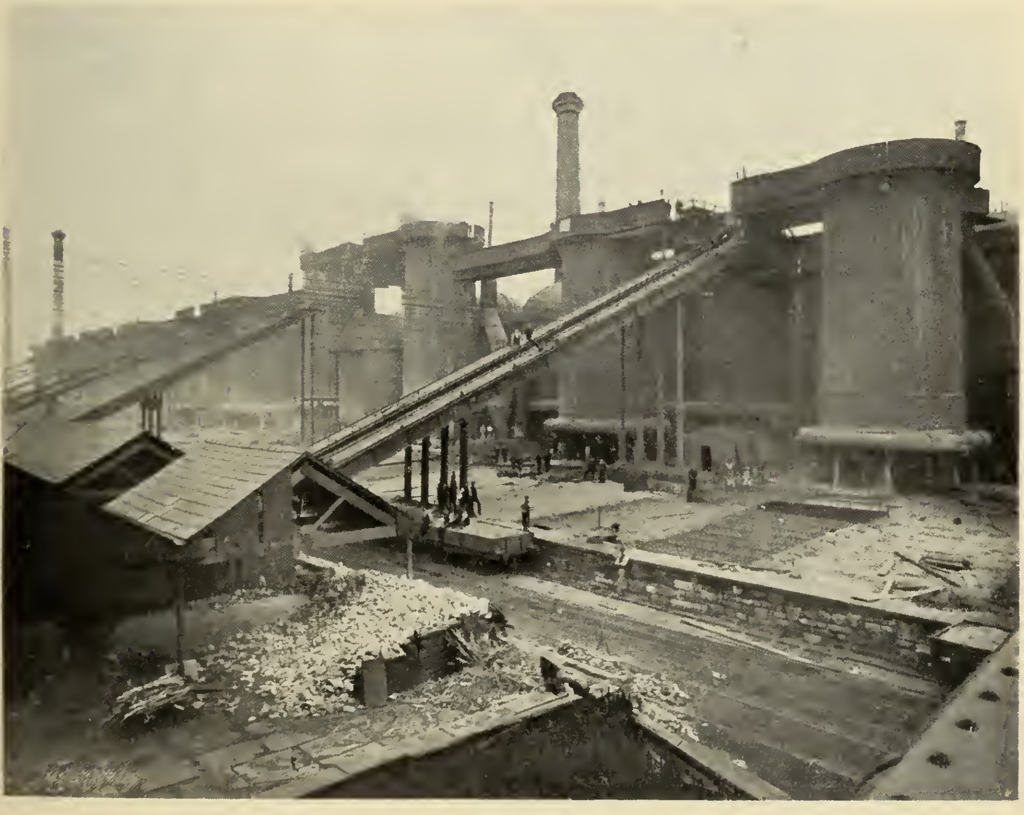
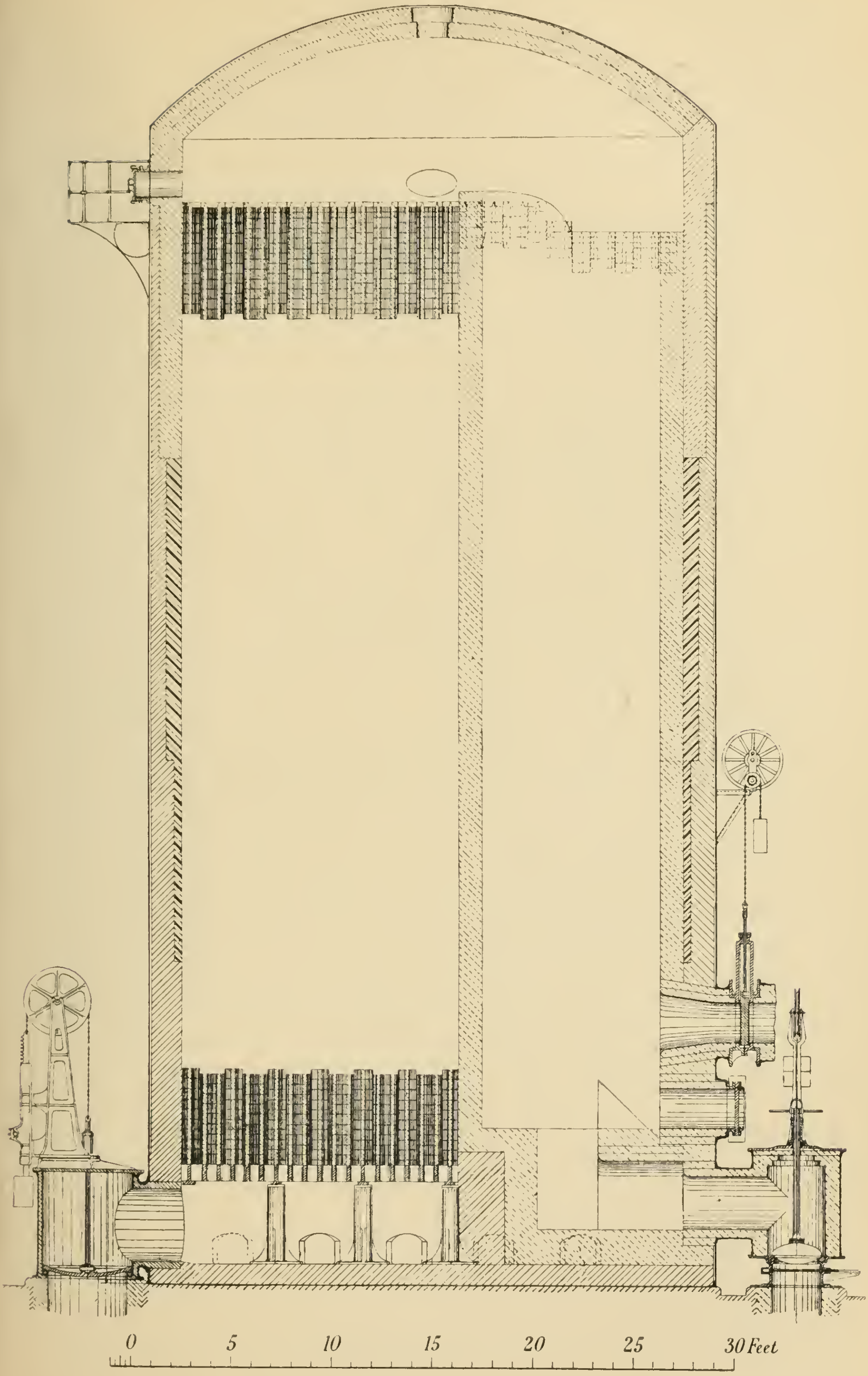


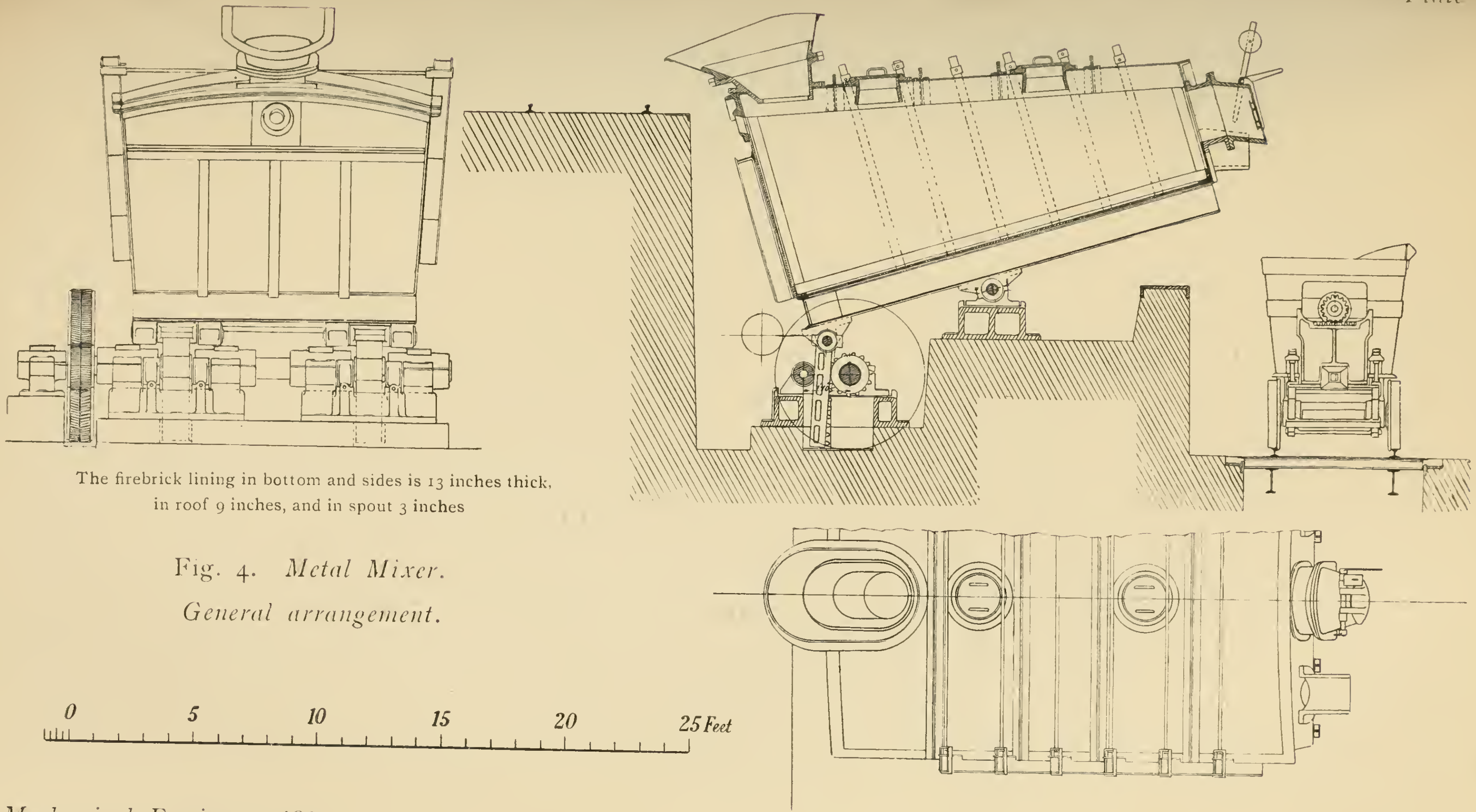
Fig. 2. *Blast Furnaces.*



BARROW STEEL WORKS.

Fig. 3. *Cowper Stove, 28-feet diam.*





The firebrick lining in bottom and sides is 13 inches thick, in roof 9 inches, and in spout 3 inches

Fig. 4. *Metal Mixer.*

General arrangement.

BARROW STEEL WORKS.

Fig. 5. *Slag Bogie.*

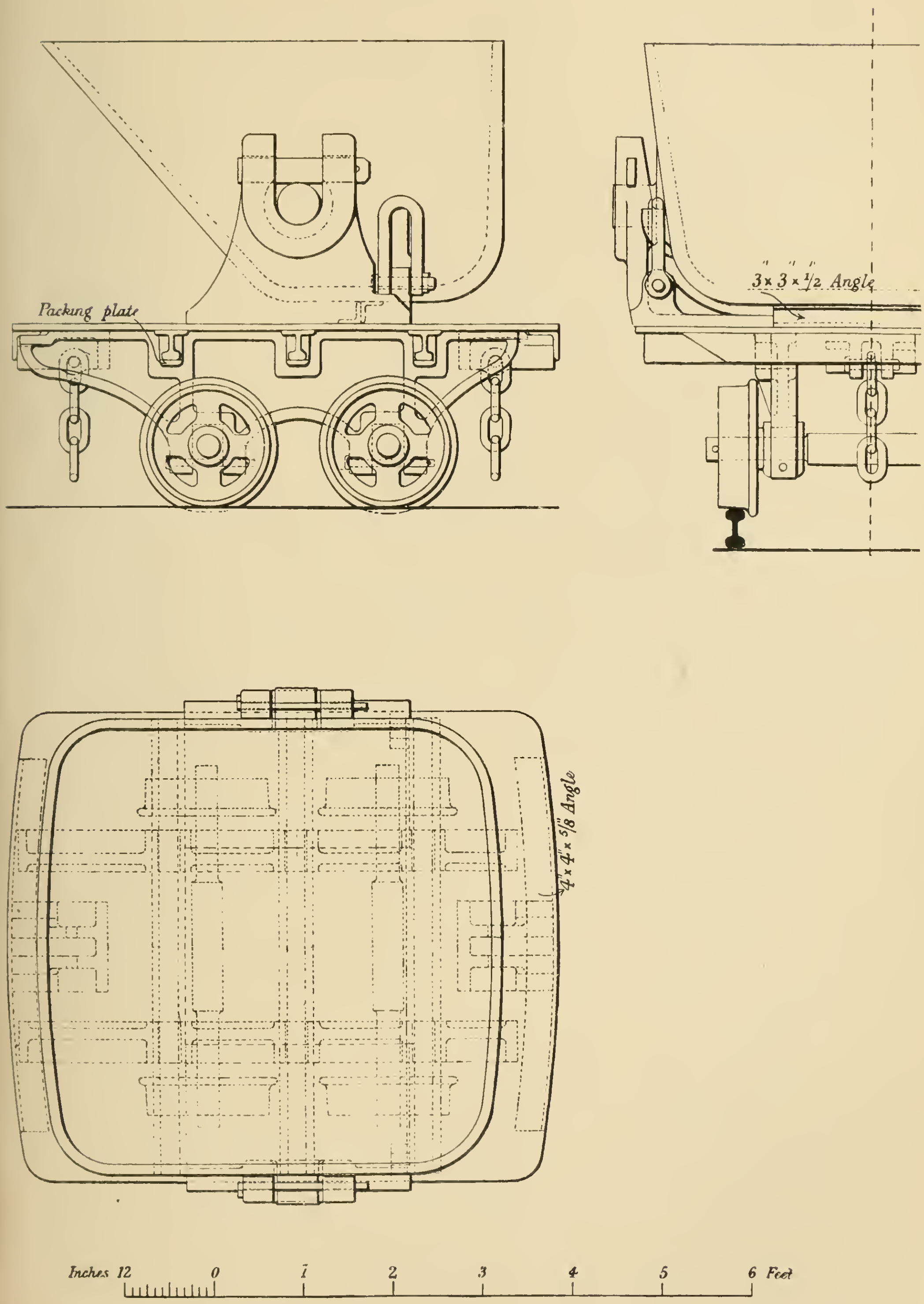
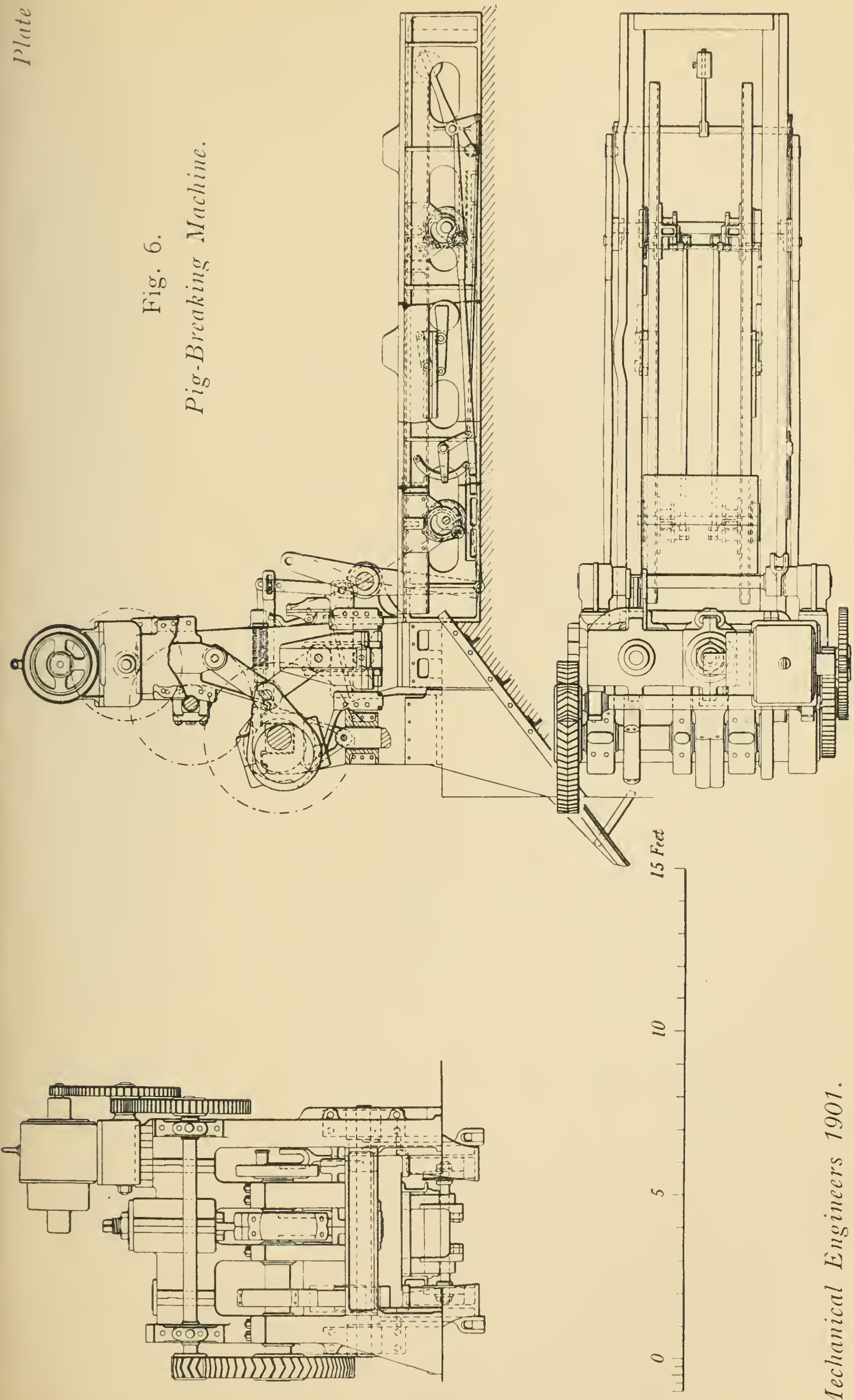


Fig. 6.

Pig-Breaking Machine.



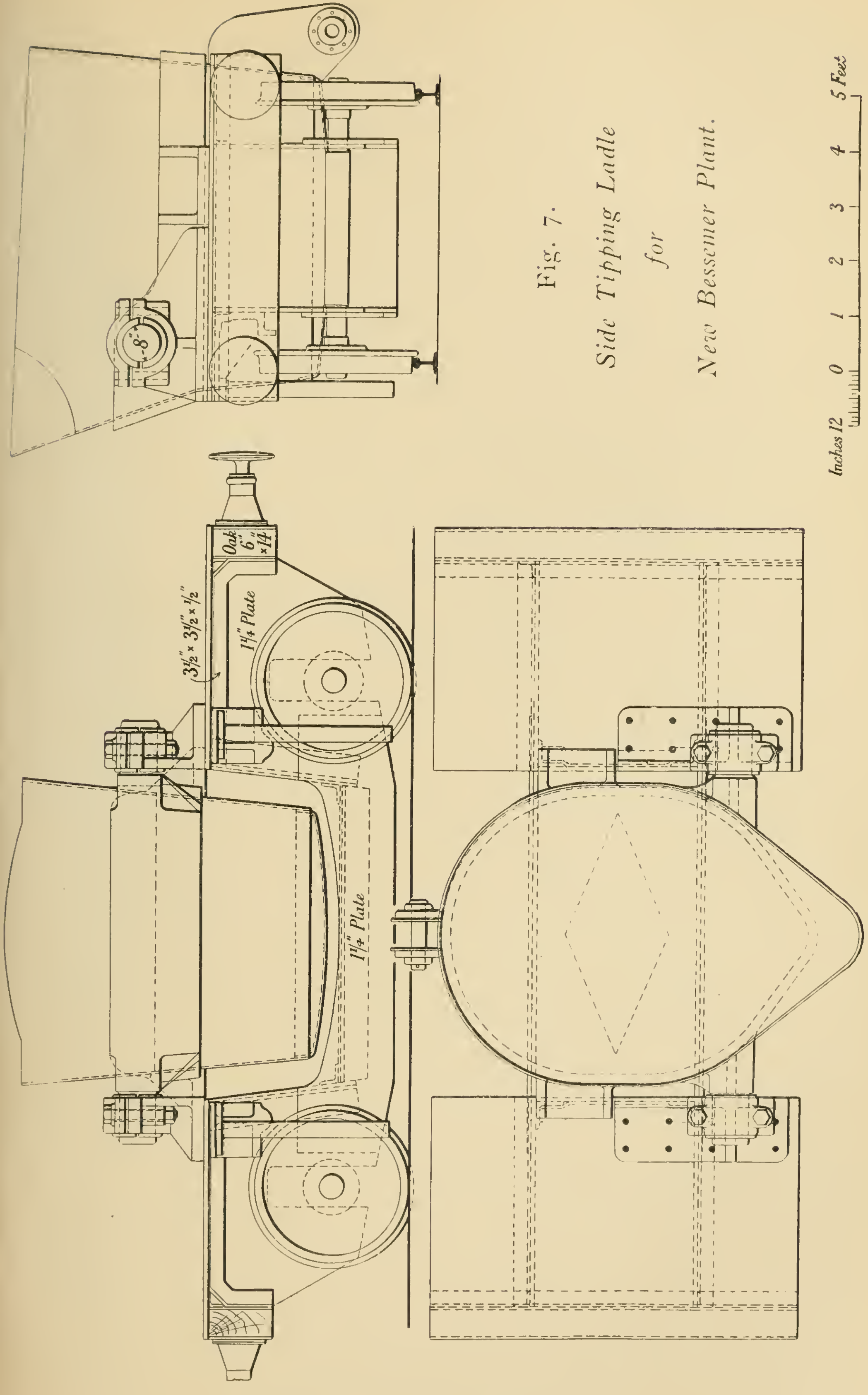
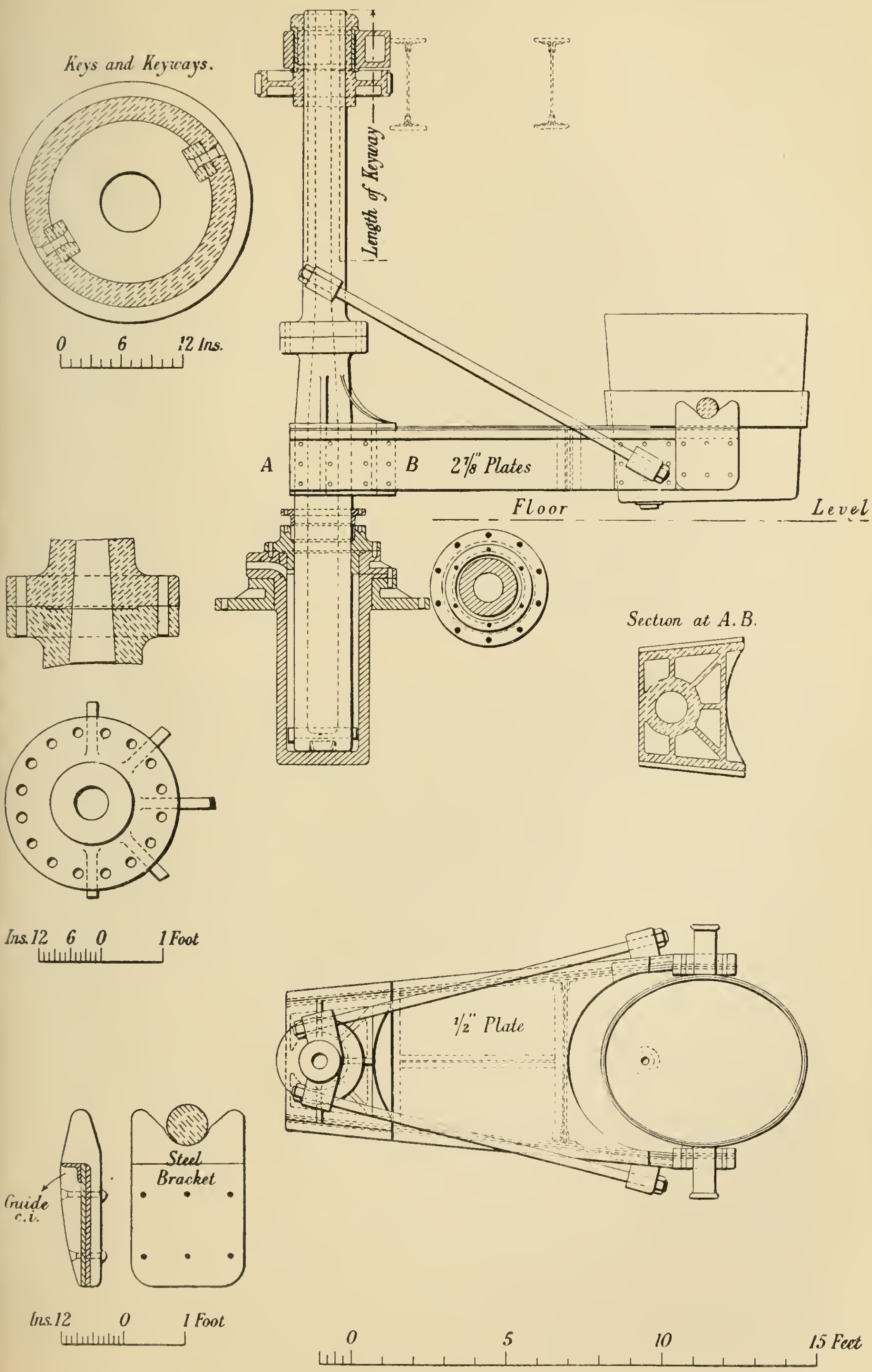


Fig. 7. Side Tipping Ladle for New Bessemer Plant.

Fig. 8. *Receiving Crane for Bessemer Shop.*



BARROW STEEL WORKS.

Fig 9. *Cogging Mill.*

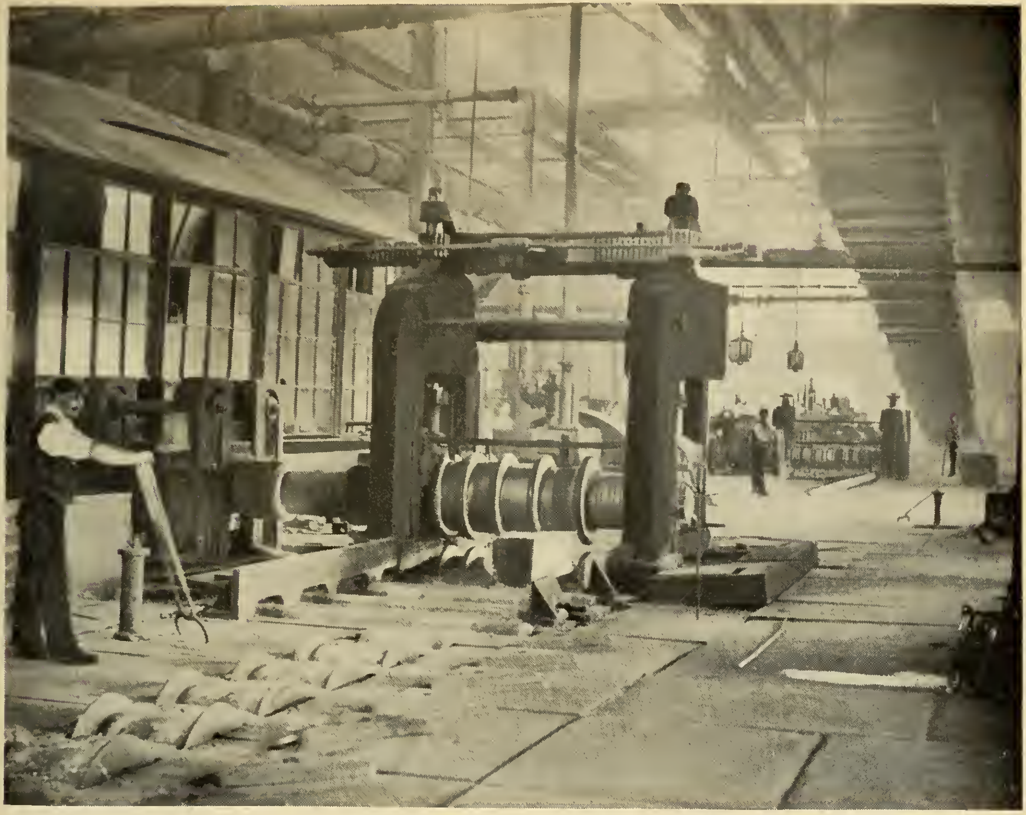
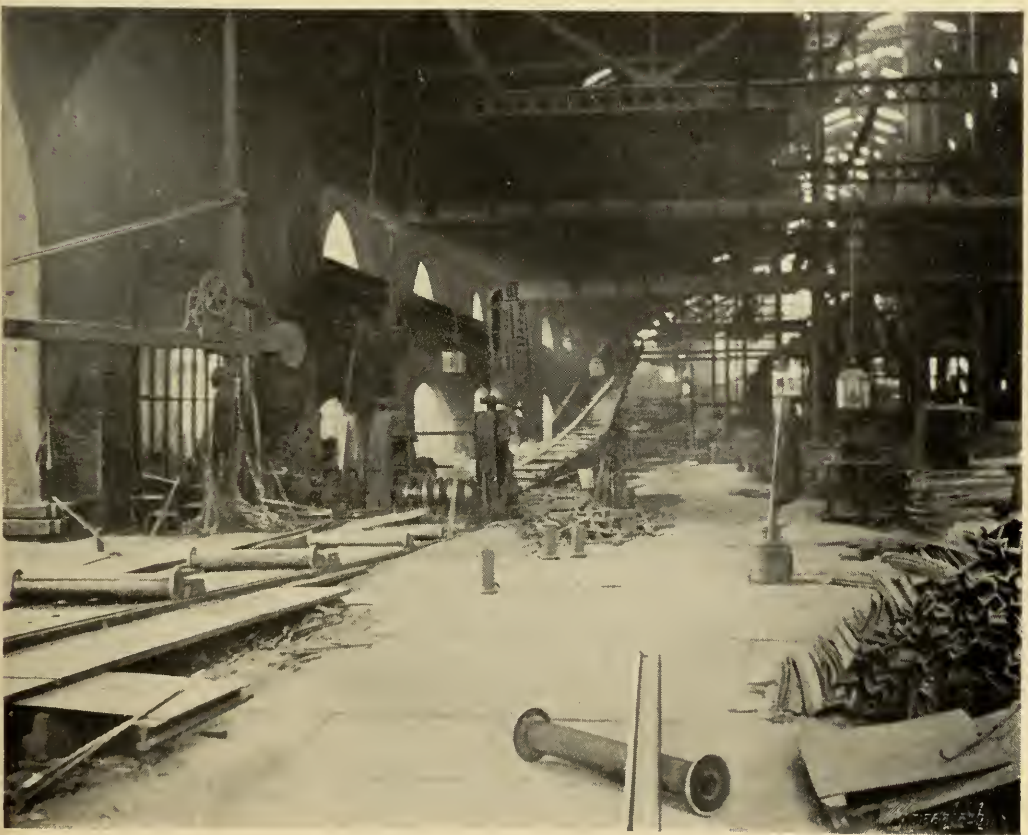


Fig. 10. *Rail Mill.*



BARROW STEEL WORKS.

50-ton Steel Melting Furnace.

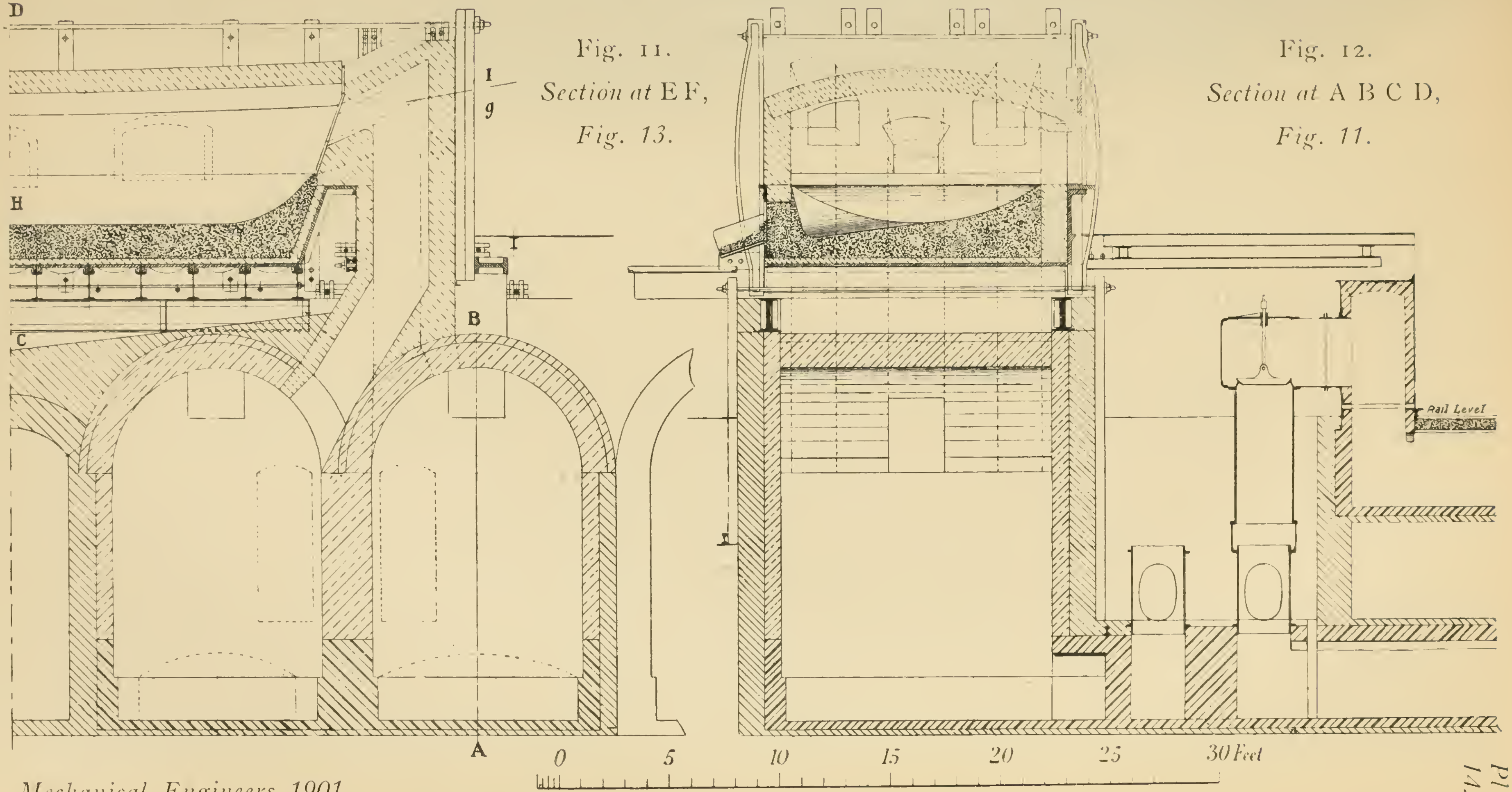
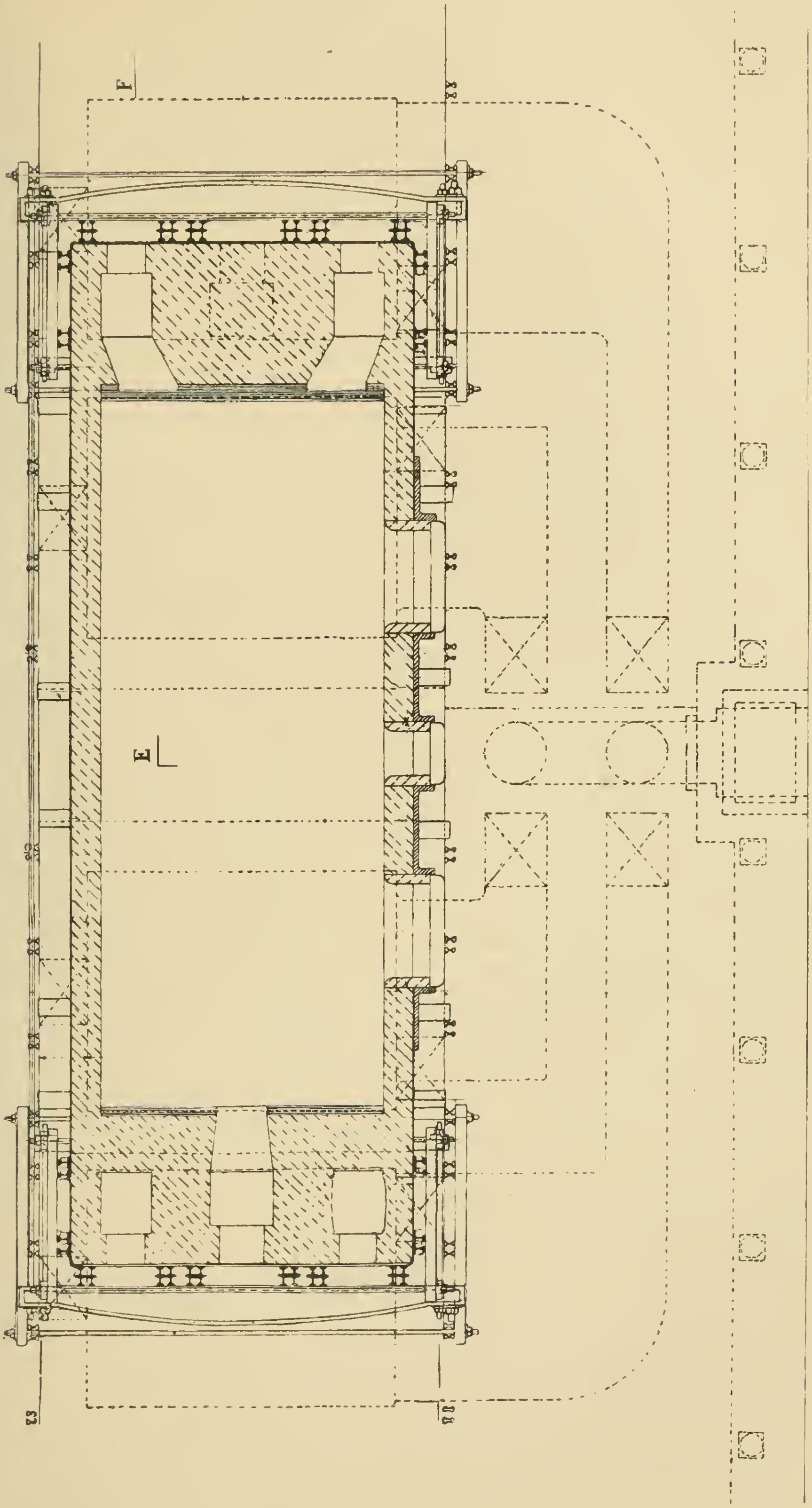


Fig. 11.
Section at E F,
Fig. 13.

Fig. 12.
Section at A B C D,
Fig. 11.

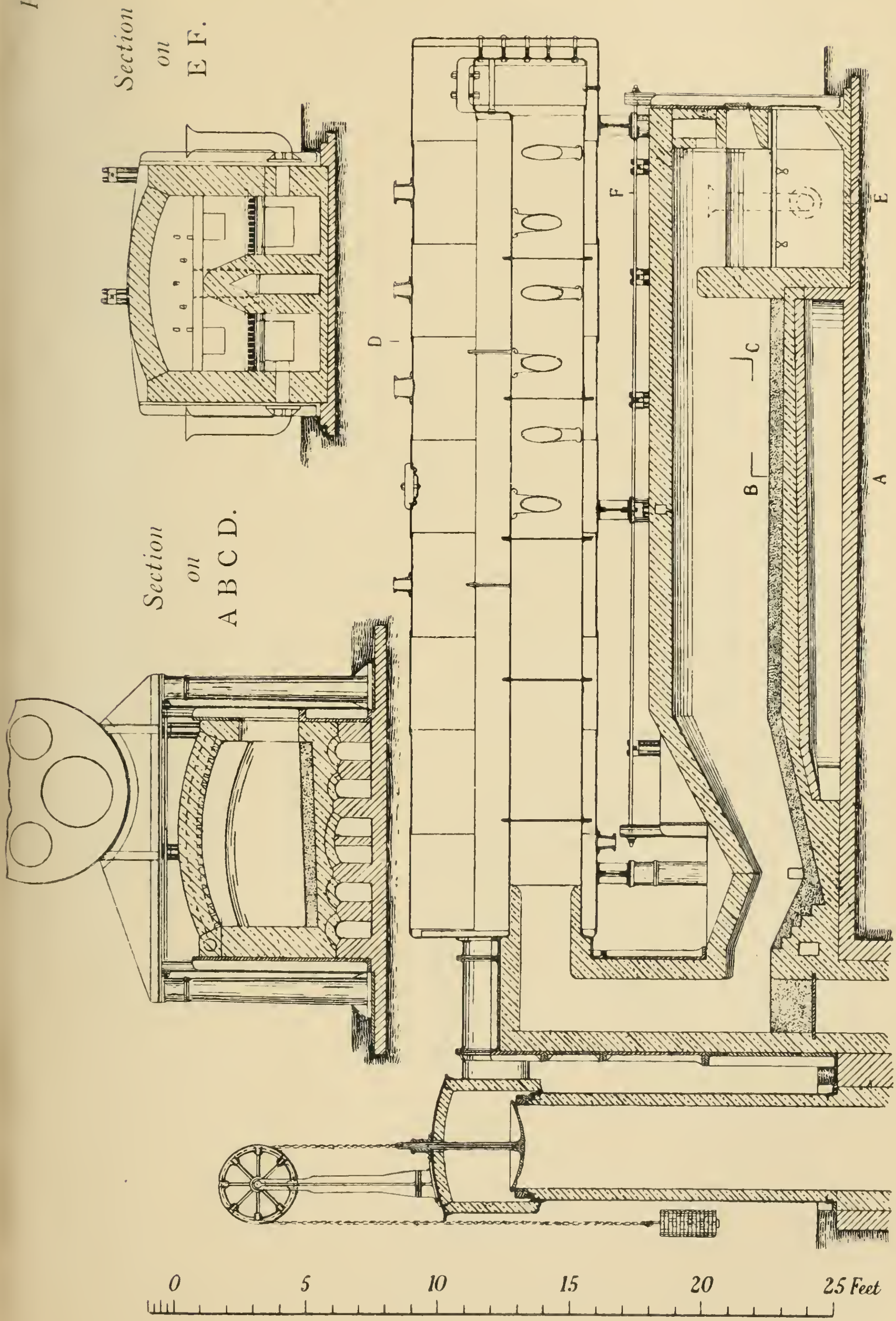
50-ton Steel Melting Furnace.

Fig. 13. *Section at g H I. Fig. 11.*



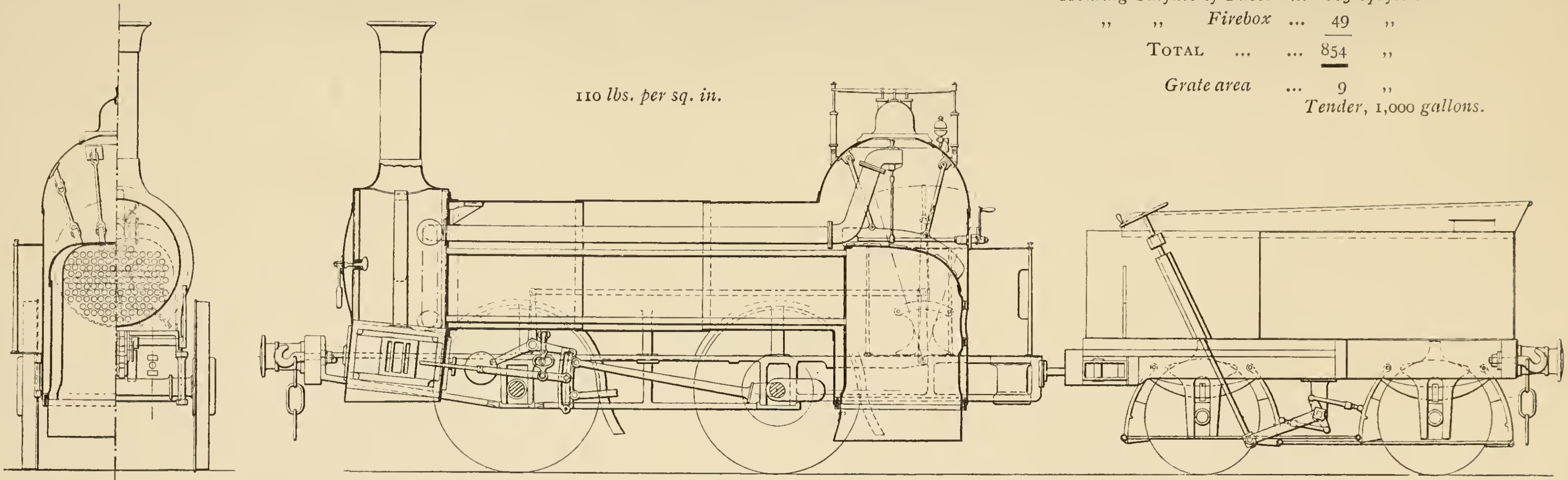
Scale, see Plate 142.

Fig. 14. *Coal Furnace and Boiler.*



FURNESS RAILWAY LOCOMOTIVES.

Fig. 1. *Bury's "Old Copper Nob," Passenger Engine, 1846.*



Heating Surface of Tubes ... 805 *sq. feet.*
,, ,, *Firebox* ... 49 ,,
Total ... ... 854 ,,
Grate area ... 9 ,,
Tender, 1,000 *gallons.*

110 *lbs. per sq. in.*

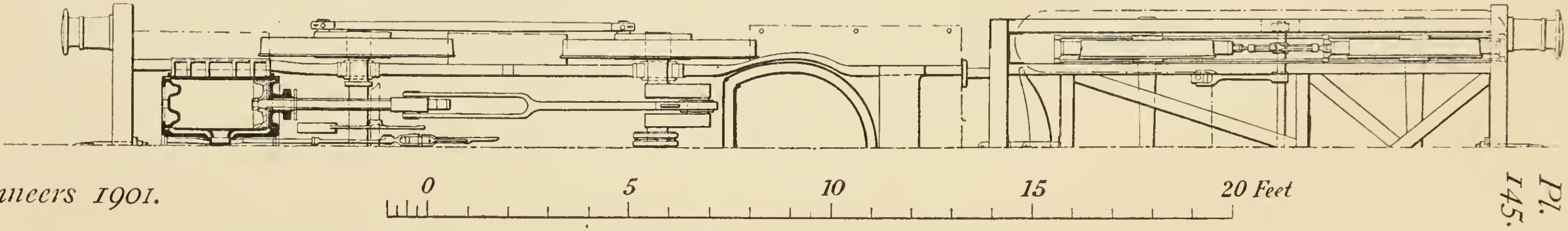
	T.	C.		T.	C.			T.	C.	T.	C.		T.	C.		T.	C.
Weight Empty ...	6	9	... ...	9	2	...	Total ...	15	11	5	7	... ...	4	18	Tot.	10	5
,, *Working* ...	7	13	... ...	11	17	...	,, ...	19	10	6	18	... ...	6	0	,,	12	18

,, *per foot run,* 2·6 *tons.*

Weight of tender per foot run, 1·9 *tons.*

Total Weight of Engine and Tender in Working Order, 32 *tons,* 8 *cwts.*

Cyls. 14 *in.* × 24 *in.*

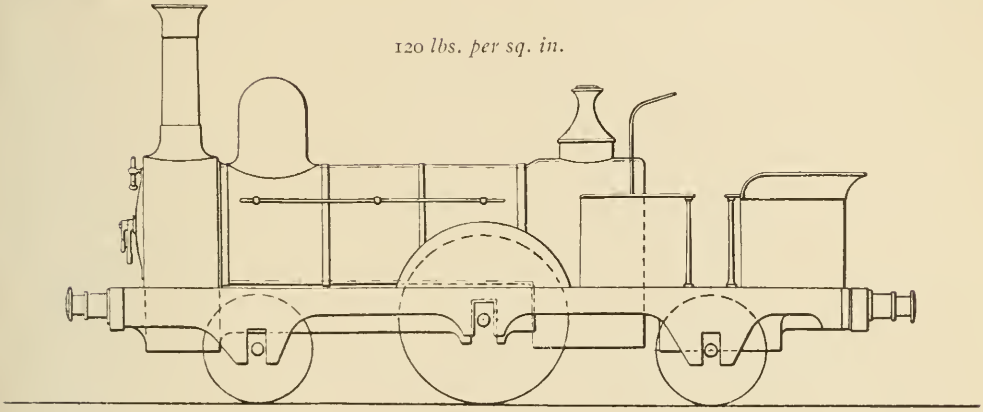


FURNESS RAILWAY LOCOMOTIVES. *Plate 146.*

Fig. 2. *Tank Engine, 1852.*

Heating Surface of Tubes ... 780 *sq. feet.*
,, ,, *Firebox* ... 55 ,,
TOTAL ... ... 835 ,,
Cyls. 14 *in.* × 18 *in.* *Grate area* ... 9 ,,

120 *lbs. per sq. in.*



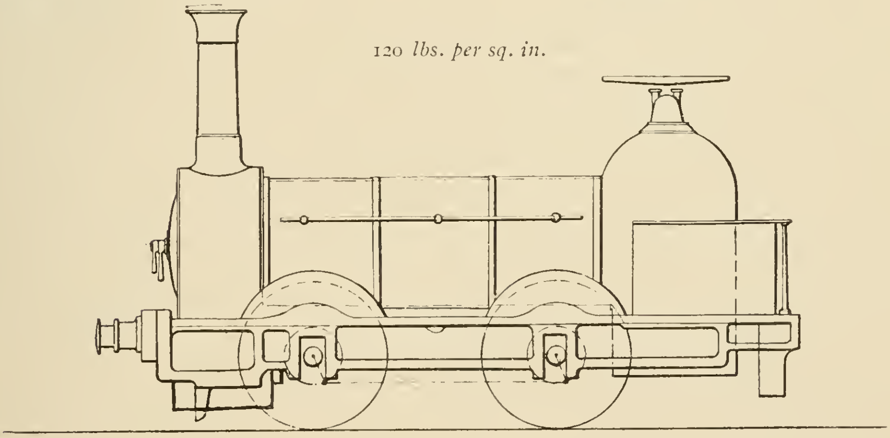
	T.	C.		T.	C.		T.	C.			T.	C.
Weight Empty ...	7	15	...	10	5	...	7	13	...	Total ...	25	13
,, *Working* ...	8	5	...	11	10	...	10	10	...	,, ...	30	5

,, *per foot run*, 2·07 *tons.* *Fuel*, 25 *cwts.* *Tanks*, 560 *gallons.*

Fig. 3. *Fairbairn's Coupled Engine, 1854-5.*

Heating Surface of Tubes ... 891 *sq. feet.*
,, ,, *Firebox* ... 49 ,,
TOTAL ... ... 940 ,,
Cyls. 15 *in.* × 24 *in.* *Grate area* ... 9 ,,

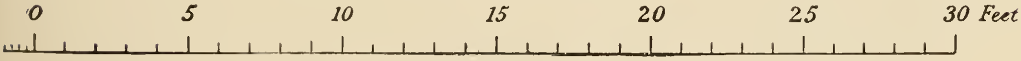
120 *lbs. per sq. in.*



	T.	C.			T.	C.			T.	C.
Weight Empty ...	7	12	...	...	10	7	...	Total ...	17	19
,, *Working* ...	8	18	...	...	12	11	...	,, ...	21	9

,, *per foot run*, 2·76 *tons.* *Tender*, 1,000 *gallons.*

Scale
(for all Locomotives except Fig. 1.)



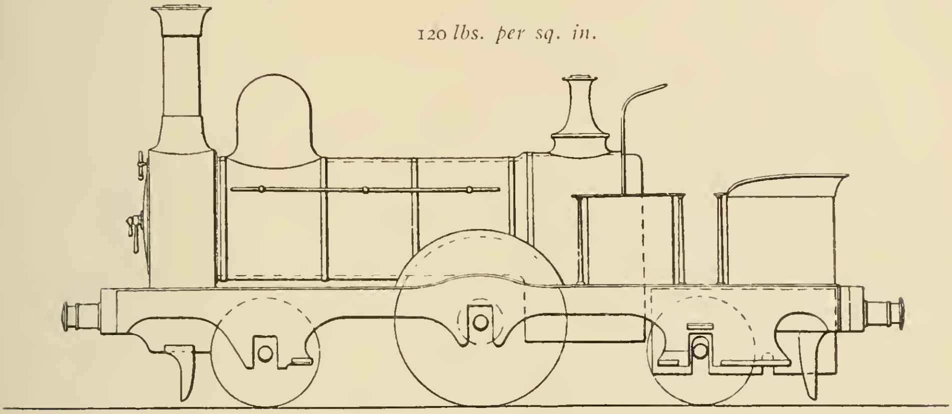
FURNESS RAILWAY LOCOMOTIVES. *Plate 147.*

Fig. 4. *Passenger Tank Engine, 1864.*

Heating Surface of Tubes	...	788	*sq. feet.*
,, ,, *Firebox*	...	70	,,
TOTAL	...	858	,,
Grate area	...	11·5	,,

Cyls. 15 *in.* × 18 *in.*

120 *lbs. per sq. in.*



	T.	C.		T.	C.		T.	C.				T.	C.
Weight Empty ...	7	19	...	10	6	...	7	14	...	Total	...	25	19
,, *Working* ...	8	4	...	11	14	...	10	7	...	,,	...	30	5

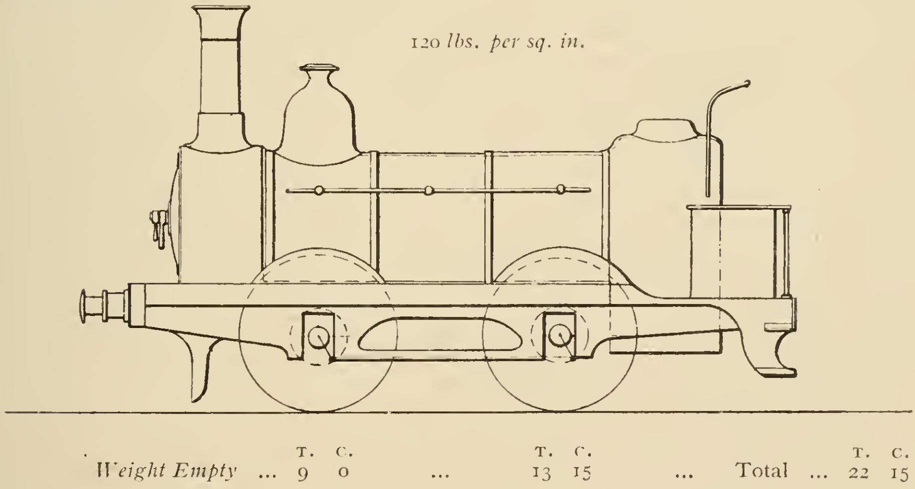
,, *per foot run,* 2·12 *tons.* *Fuel,* 25 *cwts.* *Tanks,* 560 *gallons.*

Fig. 5. *Goods Engine, 1866.*

Heating Surface of Tubes	...	870	*sq. feet.*
,, ,, *Firebox*	...	56	,,
TOTAL	...	926	,,
Grate area	...	9·2	,,

Cyls. 15½ *in.* × 24 *in.*

120 *lbs. per sq. in.*



	T.	C.		T.	C.				T.	C.
Weight Empty ...	9	0	...	13	15	...	Total	...	22	15
,, *Working* ...	9	18	...	15	0	...	,,	...	24	18

,, *per foot run,* 3·2 *tons.* *Tender,* 1,500 *gallons.*

Scale
(for all Locomotives except Fig. 1.)

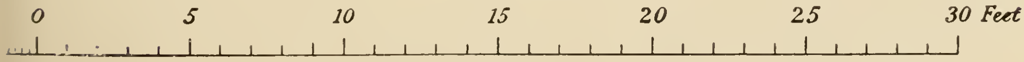
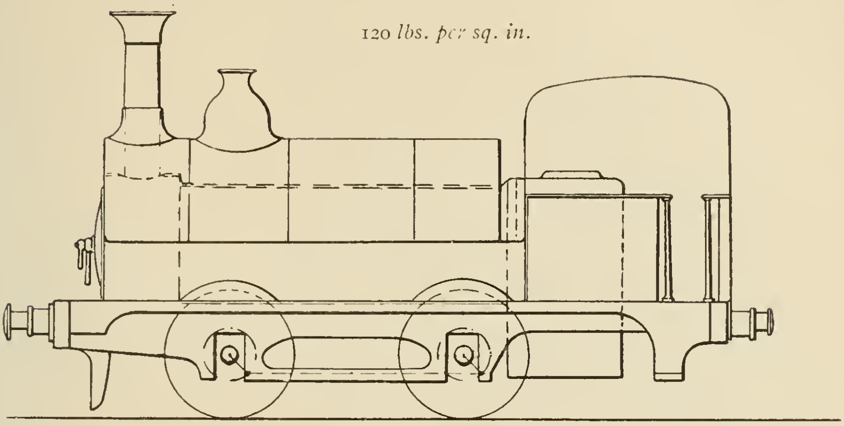


Fig. 6. *Saddle-Tank Shunting Engine, 1864.*

Heating Surface of Tubes ...	613·5	*sq. feet.*
,, ,, *Firebox* ...	55·5	,,
TOTAL	669·0	,,
Grate area ..	9·9	,,

Cyls. 14 *in.* × 20 *in.*

120 *lbs. per sq. in.*



	T.	C.		T.	C.			T.	C.
Weight Empty ...	6	19	...	14	10	...	Total ...	21	9
,, *Working* ...	8	18	...	15	12	...	,, ...	24	10

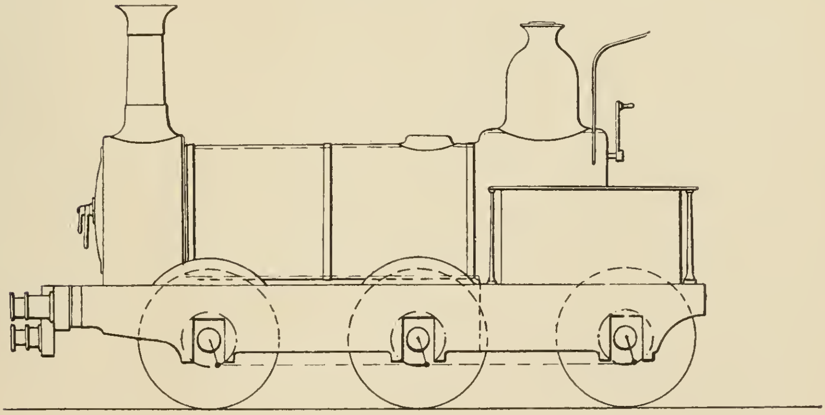
,, *per foot run*, 3·26 *tons.* *Fuel*, 12 *cwts.* *Tank*, 600 *gallons.*

Fig. 7. *Goods Engine, 1864.*

Heating Surface of Tubes ...	8 6	*sq. feet.*
,, ,, *Firebox* ...	72	,,
TOTAL	918	,,
Grate area ...	11·5	,,

Cyls. 16 *in.* × 24 *in.*

120 *lbs. per sq. in.*



	T.	C.		T.	C.		T.	C.		T.	C.
Weight Empty ...	7	15	...	9	0	...	7	10	... Total ...	24	5
,, *Working* ...	10	10	...	9	14	...	8	2	... ,, ...	28	

,, *per foot run*, 2·3 *tons.* *Tender*, 1,600 *gallons.*

Scale
(for all Locomotives except Fig. 1.)

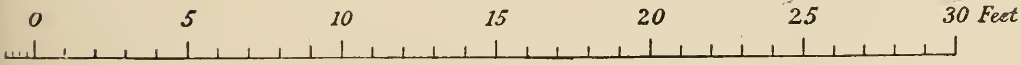
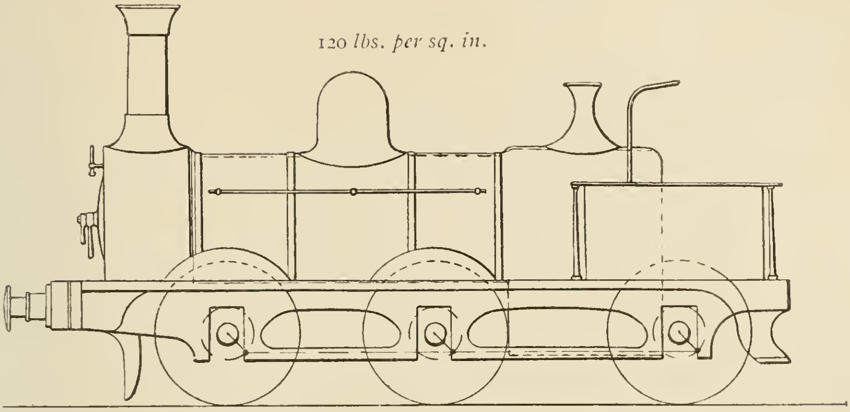


Fig. 8. *Six Wheels Coupled Goods Engine, 1866.*

Heating Surface of Tubes	...	871·27	*sq. feet.*
,, ,, *Firebox*	...	88·0	,,
TOTAL ...	..	959·27	,,
Grate area	...	13·8	,,

Cyls. 16 *in.* × 24 *in.*

120 *lbs. per sq. in.*



		T.	C.		T.	C.		T.	C.			T.	C.
Weight Empty	...	7	19	...	10	14	...	9	1	... Total	...	27	14
,, *Working*	...	10	11	...	11	10	...	8	18	... ,,	...	30	19

,, *per foot run*, 2·1 *tons.*

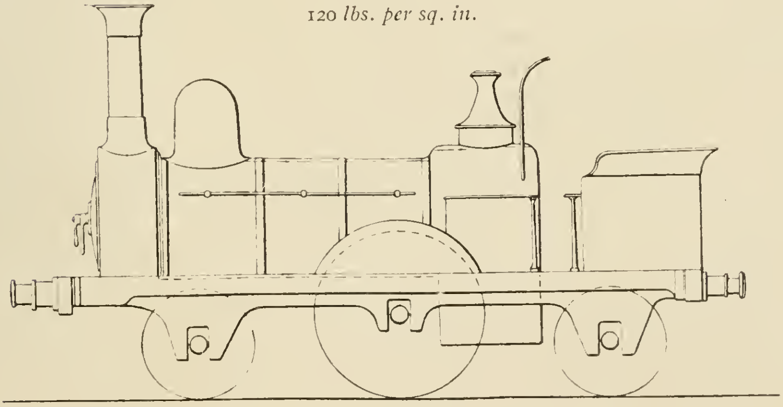
Tender, 1,500 *gallons.*

Fig. 9. *Tank Engine, 1861.*

Heating Surface of Tubes	...	690	*sq. feet.*
,, ,, *Firebox*	...	49	,,
TOTAL ...	...	739	,,
Grate area	...	8·5	,,

Cyls. 12 *in.* × 18 *in.*

120 *lbs. per sq. in.*



		T.	C.
Total Weight Empty	...	23	10
,, ,, *Working*	...	27	0

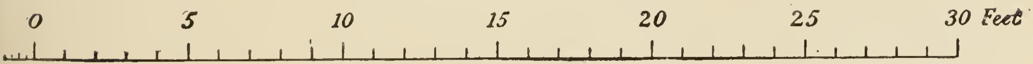
Weight per foot run, 2·03 *tons.*

Fuel, 25 *cwts.*

Tanks, 500 *gallons.*

Scale

(for all Locomotives except Fig. 1.)



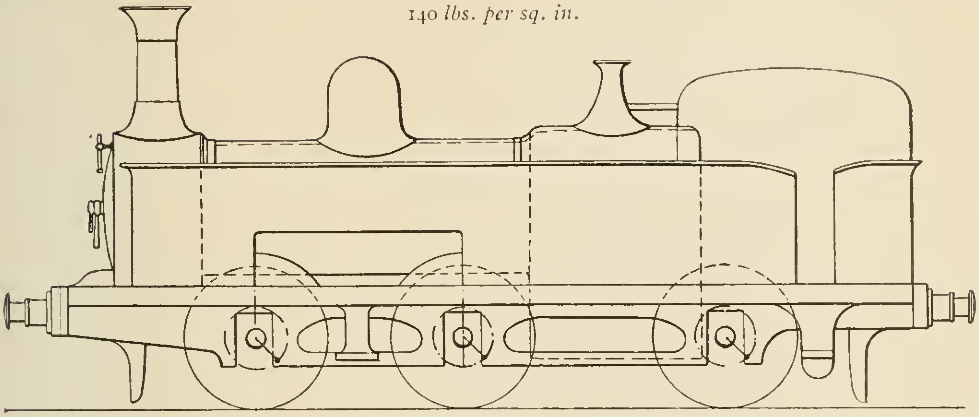
FURNESS RAILWAY LOCOMOTIVES. *Plate 150.*

Fig. 10. *Bank Engine, 1867.*

Heating Surface of Tubes ... 1,016 *sq. feet.*
,, ,, *Firebox* ... 95 ,,
TOTAL ... ... 1,111 ,,
Grate area ... 15.67 ,,

Cyls. 18 *in.* × 24 *in.*

140 *lbs. per sq. in.*



	T.	C.	T.	C.	T.	C.		T.	C.
Weight Empty ...	12	6	11	6	12	2	Total	35	14
,, *Working* ...	13	13	16	6	14	15	,,	44	14

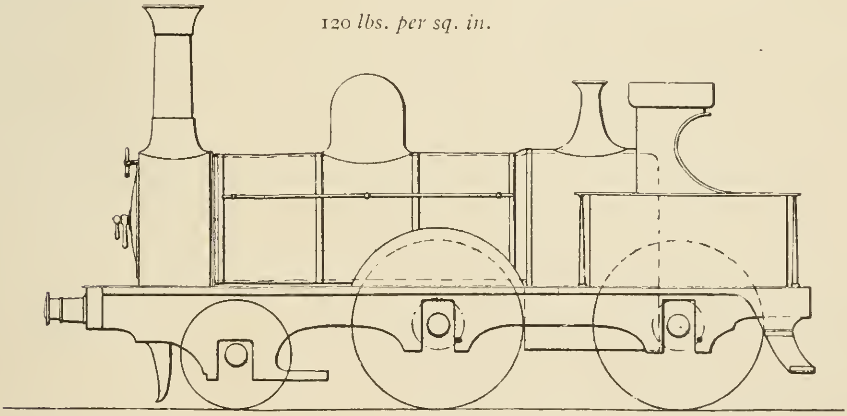
,, *per foot run,* 2·98 *tons.* *Fuel,* 30 *cwts.* *Tanks,* 1,000 *gallons.*

Fig. 11. *Passenger Engine, 1870.*

Heating Surface of Tubes ... 839·5 *sq. feet.*
,, ,, *Firebox* ... 71·0 ,,
TOTAL ... ... 910·5 ,,
Grate area ... 11·5 ,,

Cyls. 16 *in.* × 20 *in.*

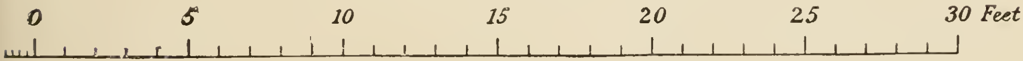
120 *lbs. per sq. in.*



	T.	C.	T.	C.	T.	C.		T.	C.
Weight Empty ...	7	13	9	10	10	1	Total ...	27	4
,, *Working* ...	8	10	11	10	10	5	,, ...	30	5

,, *per foot run,* 2·12 *tons.* *Tender,* 1,200 *gallons.*

Scale
(for all Locomotives except Fig. 1.)



FURNESS RAILWAY LOCOMOTIVES. *Plate 151.*

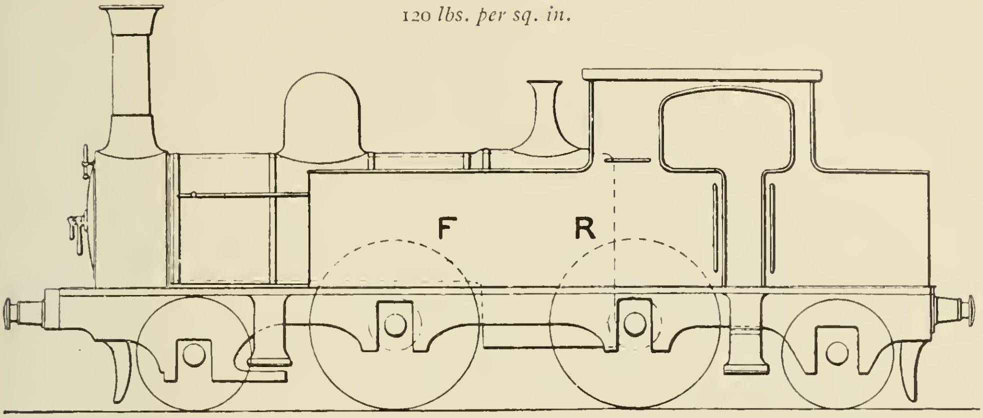
Fig. 12. *Passenger Tank Engine (Converted), 1891.*

Heating Surface of Tubes ... 839·5 *sq. feet.*
,, ,, *Firebox* ... 71·0 ,,
TOTAL ... 910·5 ,,

Cyls. 16 *in.* × 20 *in.*

Grate area ... 11·5 ,,

120 *lbs. per sq. in.*



	T.	C.		T.	C.		T.	C.		T.	C.		T.	C.
Weight Empty ...	7	7	...	11	10	...	9	10	...	7	5	Total ...	35	12
,, *Working* ...	9	15	...	12	16	...	13	13	...	8	7	,, ...	44	11

,, *per foot run*, 2·14 *tons.* *Fuel*, 32 *cwts.* *Tanks*, 1,000 *gallons.*

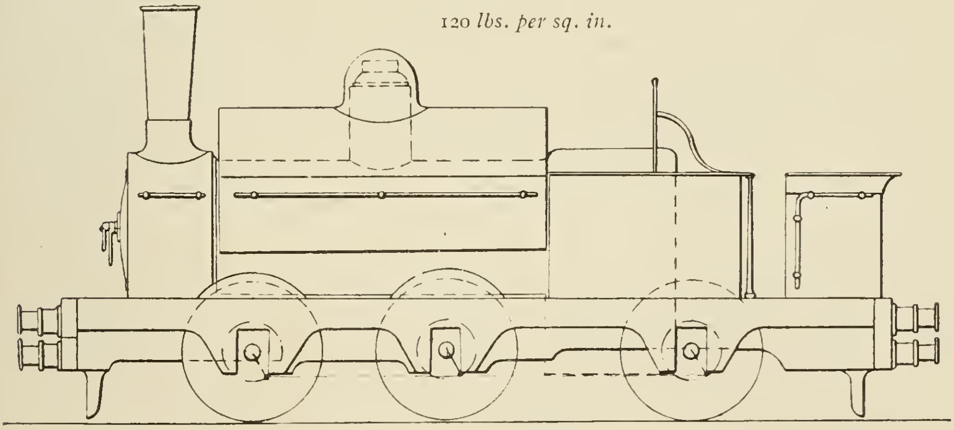
Fig. 13. *Saddle Tank Goods Engine, 1855.*

Heating Surface of Tubes ... 920 *sq. feet.*
,, ,, *Firebox* ... 75 ,,
TOTAL ... ... 995 ,,

Cyls. 17 *in.* × 24 *in.*

Grate area ... 13·3 ,,

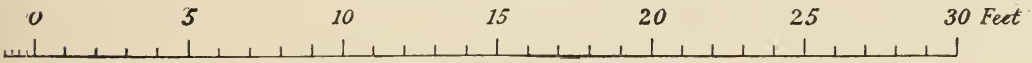
120 *lbs. per sq. in.*



	T.	C.		T.	C.		T.	C.		T.	C.
Weight Empty ...	10	6	...	11	16	...	9	0	... Total ...	31	2
,, *Working* ...	14	0	...	16	0	...	14	0	... ,,	44	0

,, *per foot run*, 3·03 *tons.* *Fuel*, 25 *cwts.* *Tank* 1,000 *gallons.*

Scale
(for all Locomotives except Fig. 1.)

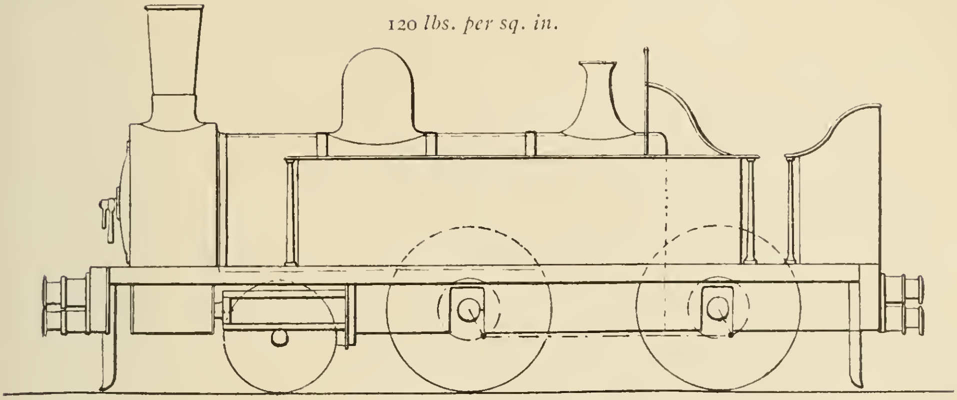


FURNESS RAILWAY LOCOMOTIVES. *Plate 152.*

Fig. 14. *Passenger Tank Engine, 1875.*

Heating Surface of Tubes ... 840 *sq. feet.*
,, ,, *Firebox* ... 71 ,,
Total ... ... 911 ,,
Cyls. 15 *in.* × 20 *in.* *Grate area* ... 11·0 ,,

120 *lbs. per sq. in.*



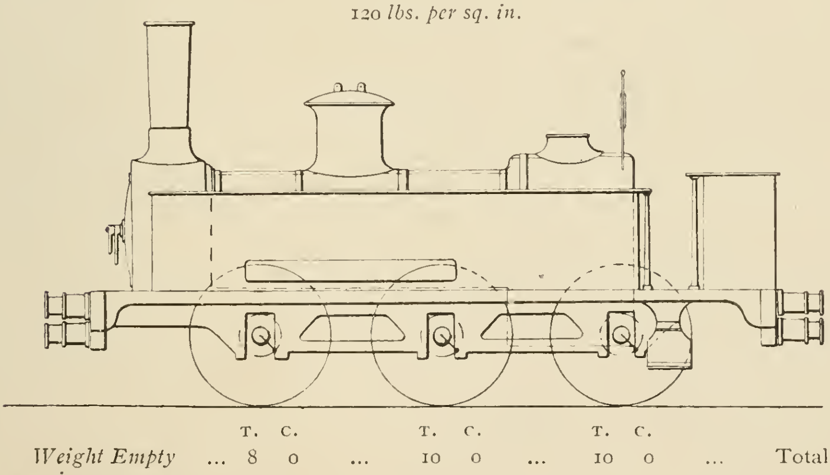
	T.	C.		T.	C.		T.	C.			T.	C.
Weight Empty ...	8	10	...	10	0	...	10	10	...	Total ...	29	0
,, *Working* ...	10	0	...	13	0	...	13	0	...	,, ...	36	0

,, *per foot run* 2·5 *tons.* *Fuel,* 25 *cwts.* *Tanks,* 1,000 *gallons.*

Fig. 15. *Side Tank Engine, 1857.*

Heating Surface of Tubes ... 718 *sq. feet.*
,, ,, *Firebox* ... 69 ,,
Total ... ... 787 ,,
Cyls. 14 *in.* × 22 *in.* *Grate area* ... 10·8 ,,

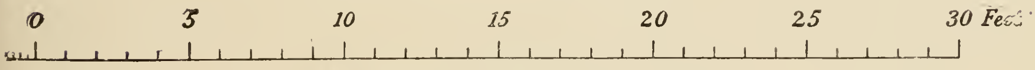
120 *lbs. per sq. in.*



	T.	C.		T.	C.		T.	C.			T.	C.
Weight Empty ...	8	0	...	10	0	...	10	0	...	Total ...	28	0
,, *Working* ...	9	0	...	12	10	...	12	10	...	,, ...	34	0

,, *per foot run,* 2·9 *tons.* *Fuel,* 25 *cwts.* *Tanks,* 800 *gallons.*

Scale
(for all Locomotives except Fig. 1.)



Mechanical Engineers 1901.

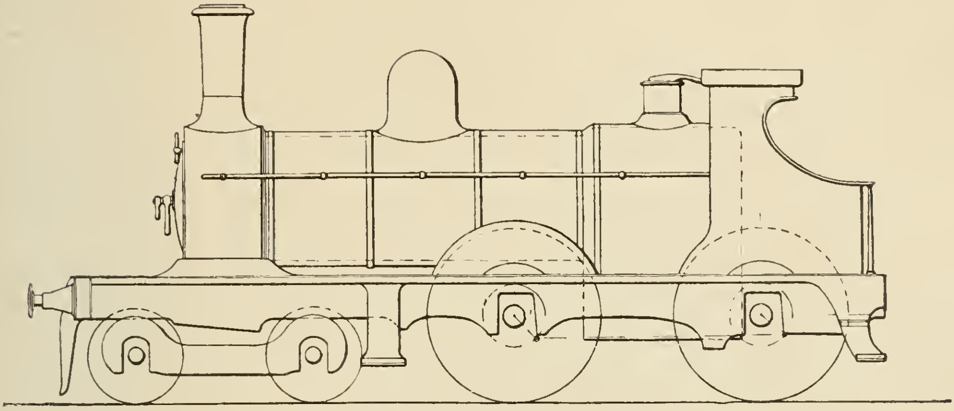
FURNESS RAILWAY LOCOMOTIVES. *Plate 153.*

Fig. 16. *Bogie Passenger Engine, 1890.*

Heating Surface of Tubes ...	955	*sq. feet.*
,, ,, *Firebox* ...	86	,,
TOTAL	1,041	,,
Grate area ...	14·2	,,

Cyls. 17 *in.* × 24 *in.*

140 *lbs. per sq. in.*



	T.	C.		T.	C.		T.	C.		T.	C.
Weight Empty ...	9	16	...	13	7	... ...	9	13	... Total	32	16
,, *Working* ...	11	12	...	12	16	... ...	11	14	... ,,	36	2

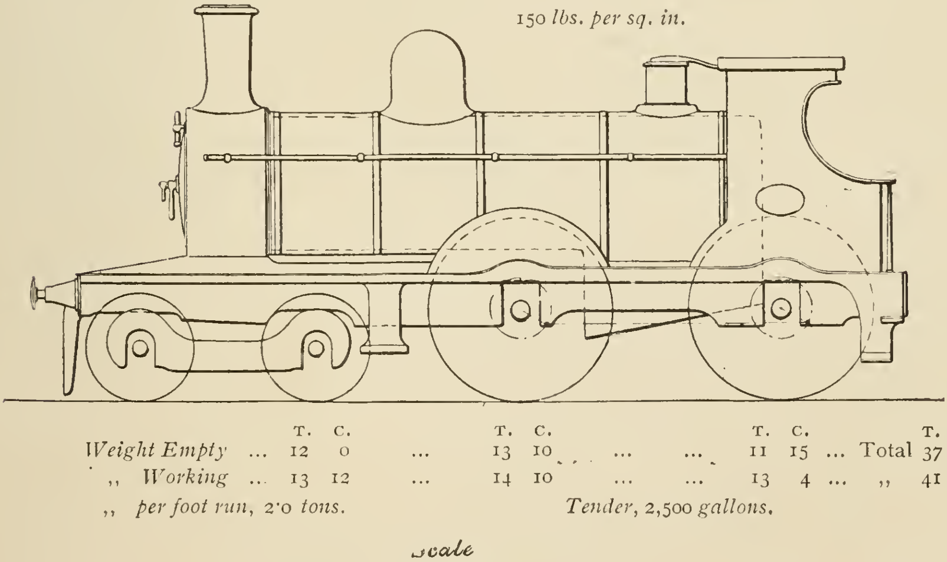
,, *per foot run,* 1·78 *tons.*

Fig. 17. *Bogie Passenger Engine, 1896.*

Heating Surface of Tubes ...	1,109	*sq. feet.*
,, ,, *Firebox* ...	99·5	,,
TOTAL	1208·5	,,
Grate area ...	17	,,

Cyls. 18 *in.* × 24 *in.*

150 *lbs. per sq. in.*

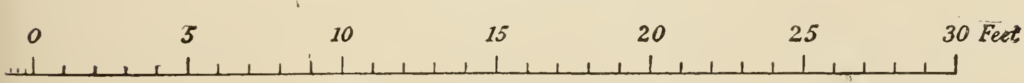


	T.	C.		T.	C.		T.	C.		T.	C.
Weight Empty ...	12	0	...	13	10	... ...	11	15	... Total	37	5
,, *Working* ...	13	12	...	14	10	... ...	13	4	... ,,	41	6

,, *per foot run,* 2·0 *tons.*

Tender, 2,500 *gallons.*

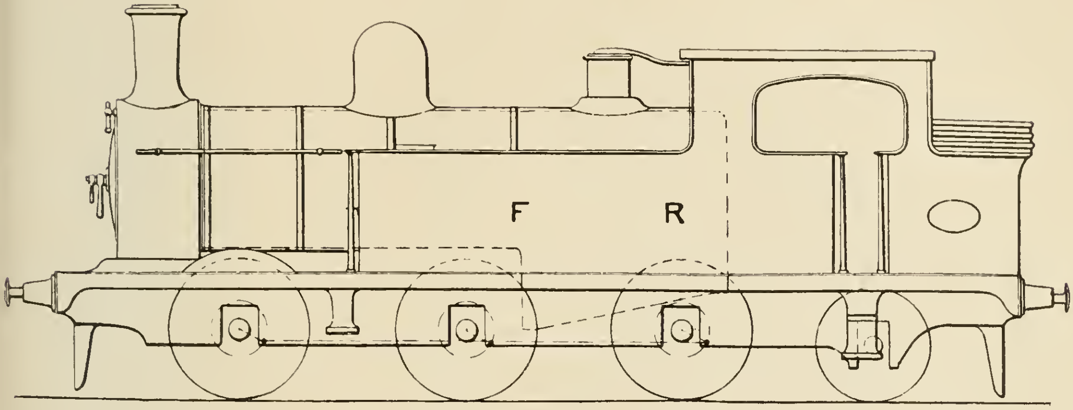
Scale
(for all Locomotives except Fig. 1.)



FURNESS RAILWAY LOCOMOTIVES. *Plate 154.*

Fig. 18. *Side-Tank Engine, 1898.*

Heating Surface of Tubes ... 1,029 *sq. feet.*
,, ,, *Firebox* ... 105 ,,
Total ... ... 1,134 ,,
Cyls. 18 *in.* × 26 *in.* *Grate area* ... 20·5 ,,
150 *lbs. per sq. in.*

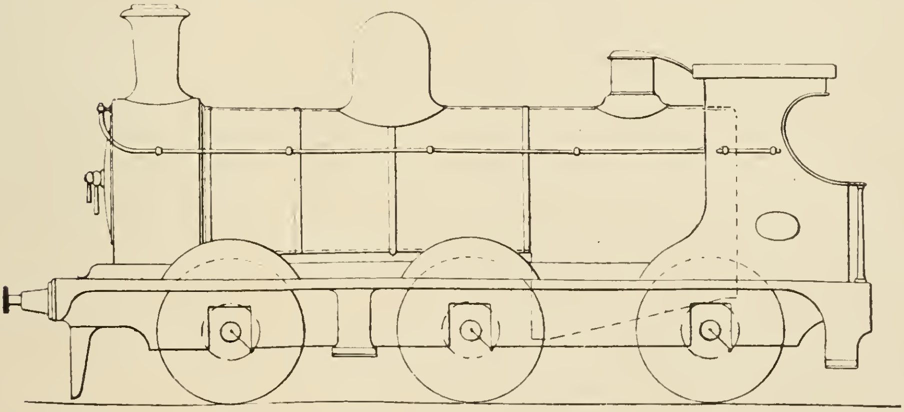


	T.	C.		T.	C.		T.	C.		T.	C.		T.	C.
Weight Empty ...	11	10	...	15	10	...	10	0	...	7	0	Total	44	0
,, *Working* ...	13	17	...	16	1	...	14	12	...	10	10	,,	55	0

,, *per foot run,* 2·65 *tons.* *Fuel,* 30 *cwts.* *Tanks,* 1,400 *gallons.*

Fig. 19. *Goods Engine, 1899.*

Heating Surface of Tubes ... 1 029 *sq. feet.*
,, ,, *Firebox* ... 105 ,,
Total ... ... 1,134 ,,
Cyls. 18 *in.* × 26 *in.* *Grate area* ... 20·5 ,,
150 *lbs. per sq. inch.*



	T.	C.		T.	C.		T.	C.		T.	C.
Weight Empty ...	11	13	...	12	15	...	11	2	Total ...	35	10
,, *Working* ...	13	0	..	13	8	...	11	15	,,	38	3

,, *per foot run,* 2·55 *tons.* *Tender,* 2,500 *gallons.*

Scale
(for all Locomotives except Fig. 1.)

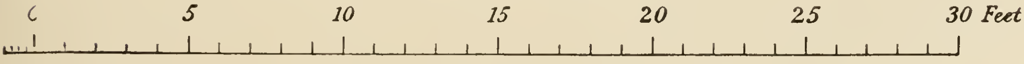


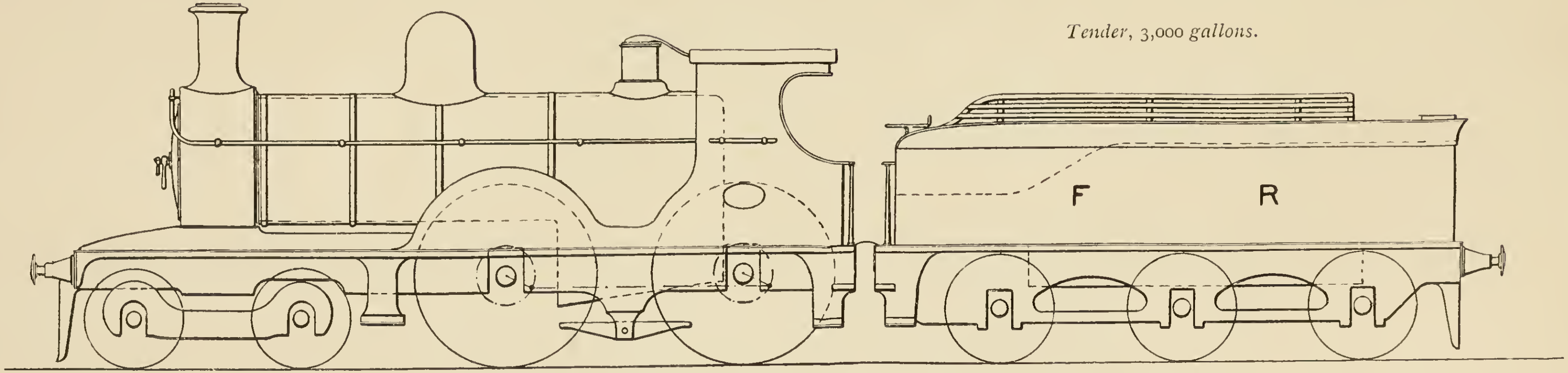
Fig. 20. *Four Wheels Coubled Bogie Passenger Engine, 1901.* *Plate 155.*

Heating Surface of Tubes ... 1,159 *sq. feet.*
,, ,, *Firebox* ... 111·5 ,,
Total ... ... 1,270·5 ,,
Grate area ... 18 ,,

Cyls. 18 *in.* × 26 *in.*

160 *lbs. per sq. in.*

Tender, 3,000 *gallons.*



	T. C.	T. C.	T. C.	T. C.	T. C.	T. C.	T. C.	T. C.
Weight Empty	13 6	12 18	12 9	Total 38 13	6 2	5 7	5 7	Total 16 16
,, *Working*	15 1	14 4	13 15	,, 43 0	10 18	11 8	10 8	,, 32 14

,, *per foot run,* 2·0 *tons.*

Weight of Tender per foot run, 2·5 *tons.*

Total Weight of Engine and Tender in Working Order, 75 *tons,* 14 *cwts.*

Scale
(for all Locomotives except Fig. 1.)

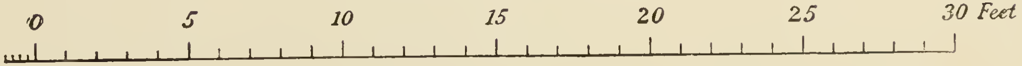
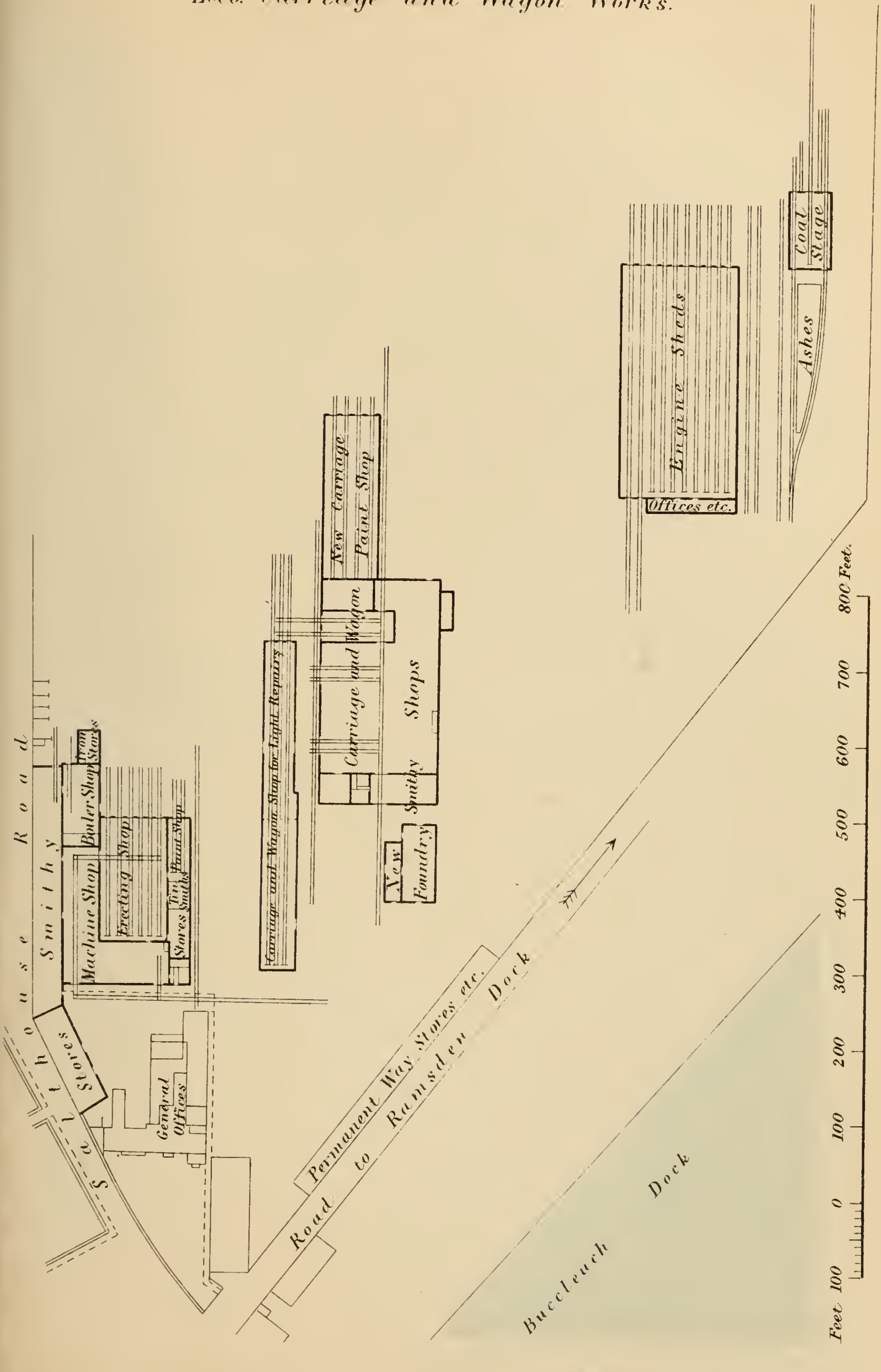
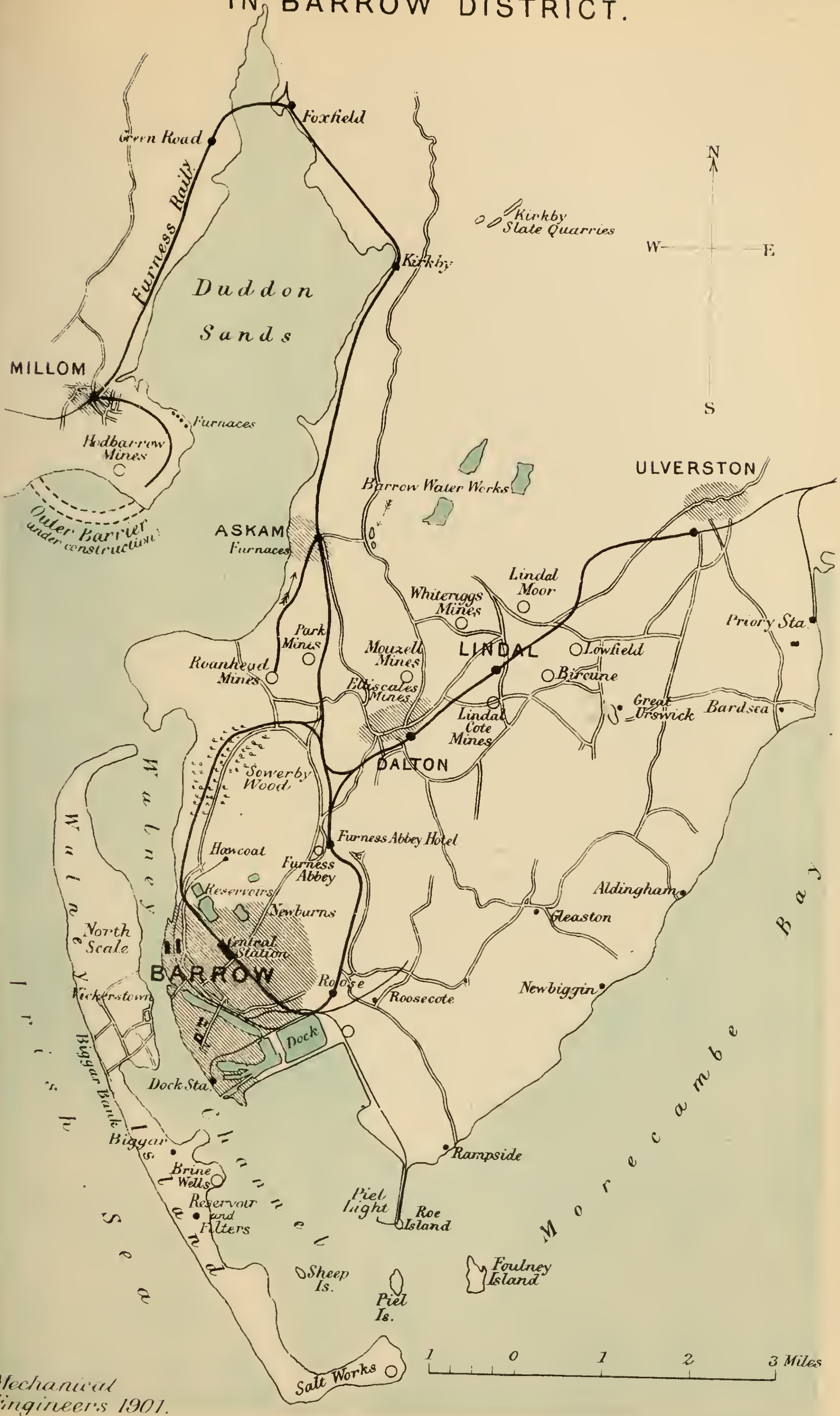


Fig: 21. Plan of Furness Railway Company's Loco. Carriage and Wagon Works.



MINES AND WORKS IN BARROW DISTRICT.

Plate 157.



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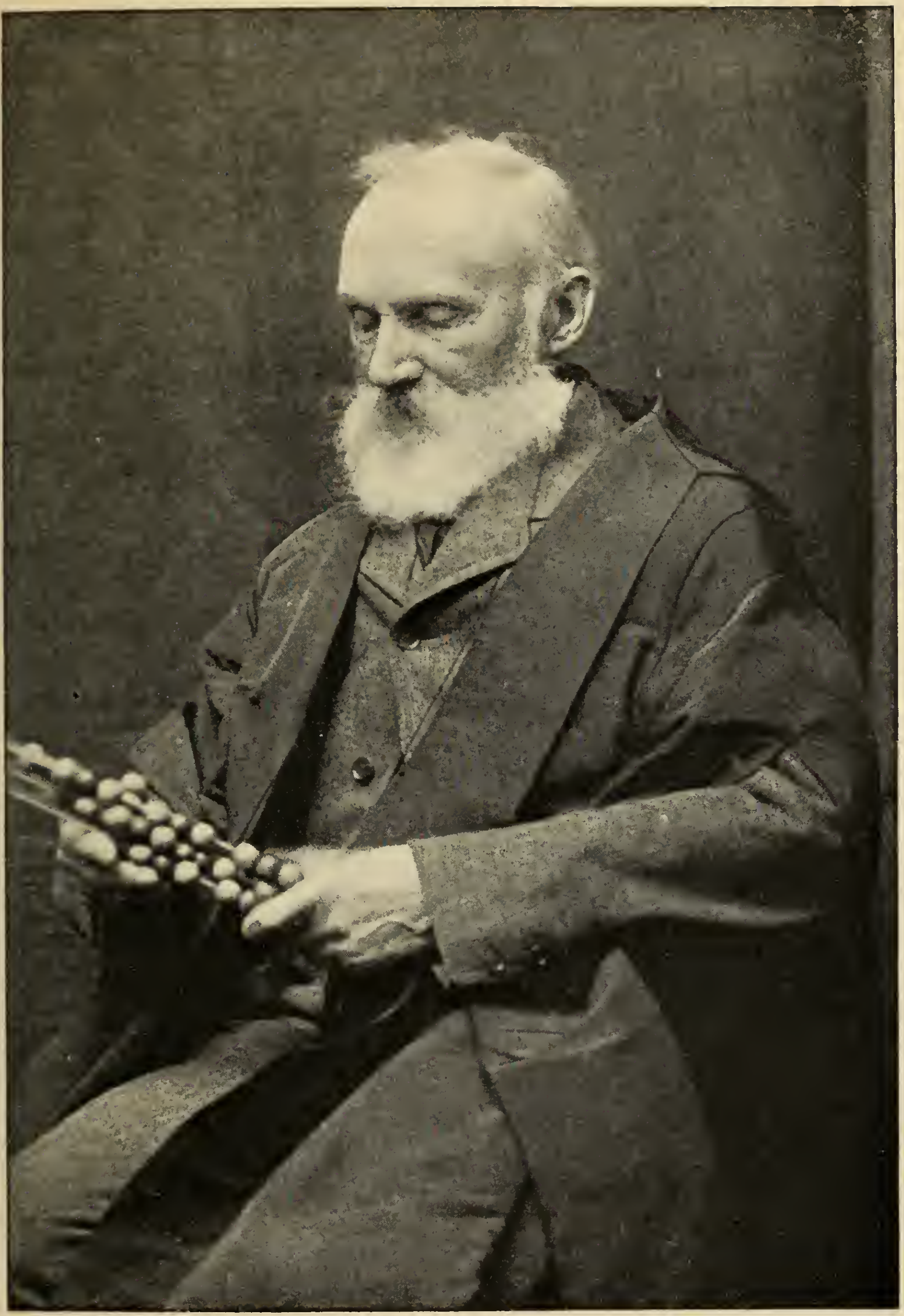

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INTERNATIONAL ENGINEERING CONGRESS, GLASGOW, 1901.

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The Institution of Mechanical Engineers.

PROCEEDINGS.

SEPTEMBER 1901.

A RECORD OF THE MECHANICAL SECTION, INTERNATIONAL ENGINEERING CONGRESS (GLASGOW) 1901.

At the invitation of the organisers of the above International Engineering Congress, Mr. William H. Maw, the President of the Institution, was invited to be Chairman of the Mechanical Section (III.) of the Congress; and the Institution undertook to arrange the various Papers and discussions which are recorded in this special part of the Proceedings.

On the opening day an Address to the whole Congress was delivered in the Bute Hall by the President of the Congress, Mr. James Mansergh, President of the Institution of Civil Engineers, after which the various Sections held their meetings in the University Buildings, on three consecutive mornings, 3rd to 5th September.

The discussions in this Section were reported in full; and abstracts of the same, revised by the speakers, are incorporated in the present volume.

The CHAIRMAN of the Mechanical Section, in opening the proceedings of the Section which met in the Students' Union Debating Hall, said that there was a large amount of work to get through, and he would not trouble them with any introductory remarks of his own. He would only explain that it was proposed to take on the first day Papers relating to Motors, on the following day the Papers relating to Workshop Methods, while on the third day the miscellaneous subjects would be dealt with.

THE COOLING OF THE CYLINDERS OF HIGH-SPEED INTERNAL-COMBUSTION ENGINES, AND ITS EFFECT UPON THE POWER DEVELOPED.

By Professor H. S. HELE-SHAW, LL.D., F.R.S., *Member*,
of Liverpool.

In response to an invitation to bring some subject which might be of interest before the present Engineering Congress, it occurred to the author that there was one which, though at the present time exciting attention chiefly amongst automobilists, has (in the rapid development in the powerfulness of small high-speed oil and spirit engines) a direct interest for engineers in general. This subject is the over-heating of the cylinders, and its prevention.

In comparatively large, slow running, stationary oil or gas-engines it is easy enough to have a water-jacket with one or two fairly large tanks of cooling water; but, upon a motor car, where weight is a prime consideration, the matter of cooling is one which causes great trouble, and the provision for which has involved arrangements of great ingenuity. In quite small motor vehicles, such as motor bicyles and tricycles, and even the small voiturette, —that is, with engines up to 3 H.P.—the movement of the vehicle through the air, or the provision of a revolving fan, is taken advantage of for the purpose of cooling the cylinders by air, the cylinders being provided with a small number of webs for this purpose. In a French engine which the author tested a short time ago, four cylinders, nominally of about 3 H.P., revolved at a high speed in a horizontal plane round a fixed crank-shaft, and after some hours' run in a heated workshop, it was possible to bear the hand upon the outside of the cooling ribs of the cylinders, although upon standing the heat was rapidly conducted outwards. Certain constructional defects in the engine prevent the full power being obtained; and it cannot be known until these are remedied, whether the air-cooling is really effective in this type of engine.

With small engines air-cooling is fairly effective in quite cold weather, but in hot and dry weather (which is, of course, chiefly the time when motor vehicles are in requisition) even small engines of little more than 1 H.P., rapidly become heated with a corresponding falling off in propelling power, ultimately stopping altogether. No doubt, by careful management in the way of continual regulation in the admission of gas into the carburetter, and great watchfulness in taking advantage of every descent of a hill to cool the cylinder, and, further, by being content with a moderate speed of the engines, an air-cooled cylinder of $2\frac{3}{4}$ to 3 H.P. can be kept cool even upon a fairly hot day. The author has however recently had some experience with two tricycles, one having a $2\frac{3}{4}$-H.P. engine, air-cooled, and another with a water-cooled head of the same power, the latter being the most recent type of De Dion motor, in which a small tank of water carried behind the saddle, and a small radiator, through which the water circulates by gravitation, are employed. He has no hesitation in saying that the power developed in the latter case has been very much greater than in the former, while there is no comparison whatever in the distance which can be covered on a hot day by the two machines, to say nothing of the satisfaction of being able to ride mile after mile at a high speed, without the slightest anxiety about climbing any hills which may be met, even in such a ride as from Carlisle to the east of Fife.

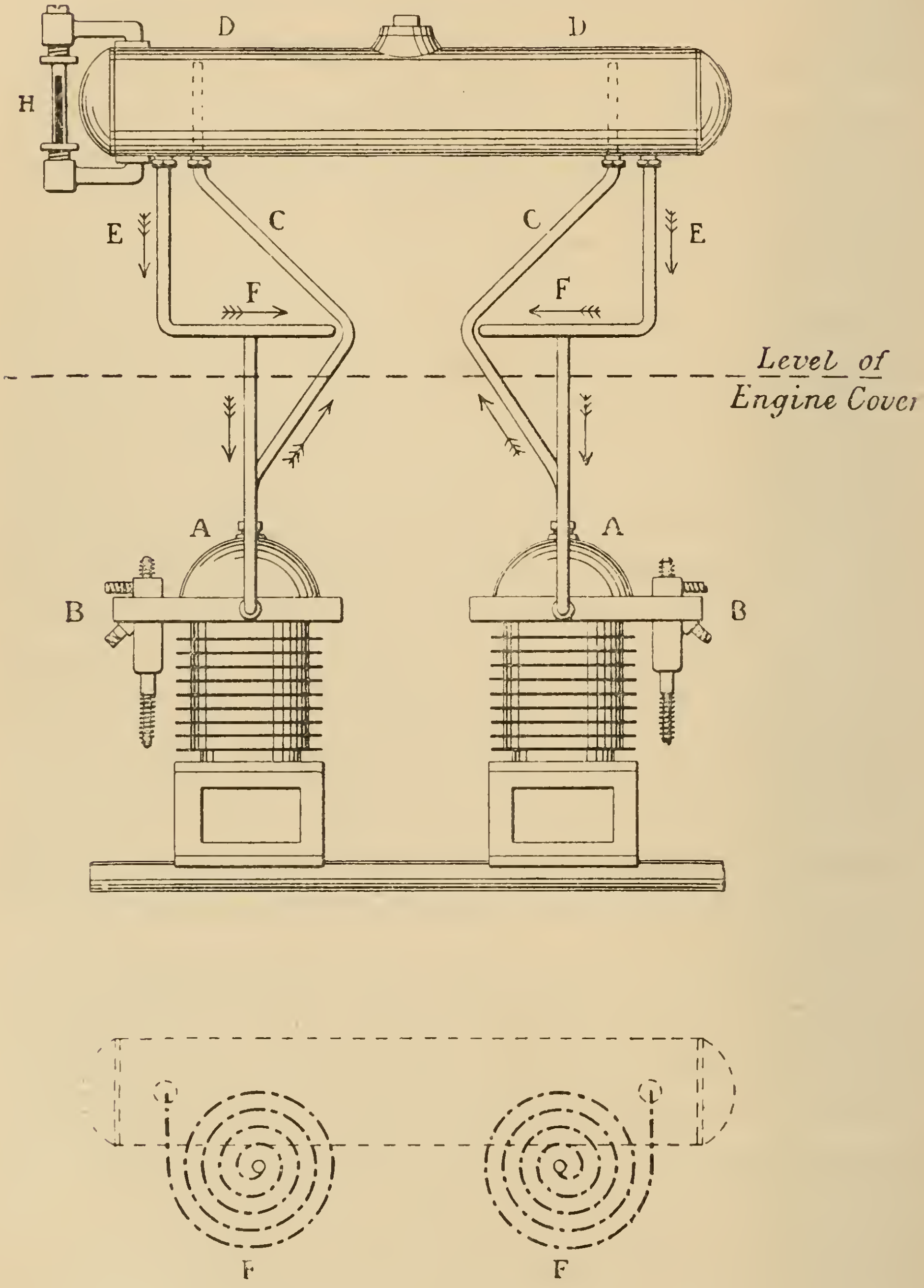
The author has had a similar experience with regard to his two-cylinder "New Orleans" voiturette. This voiturette, in spite of many defects such as are probably to be found in most motor cars, is a fast little car; and the air-cooled cylinders, which have a fan revolving between them, can, in quite cold weather, or even with an abnormal amount of care in hot weather, be made to run very well.

In hot weather, however, he has experienced so much annoyance with the heating of the cylinders upon a long run, that he first of all adopted the plan of allowing water to drop upon the air-cooled cylinder-head from a reservoir when he found the cylinder was getting hot, but afterwards decided to replace the air-cooled heads with water-cooled heads. Since doing this he has never had any trouble whatever with the heating of the cylinders, or experienced any diminution in power from this cause. On one of the hottest days of the year this voiturette went about a hundred miles, and returned a few days later without his experiencing any trouble, at any rate, from this cause. A number of communications have reached the author from people who have evidently experienced trouble with these cars, asking for details of the water-cooling arrangement; and it may, therefore, be interesting to describe briefly the details which are illustrated in a diagrammatic way in Fig. 1 (page 788). The hollow water-cooled heads AA, together with valve chambers BB, which are in one solid piece, replace the ordinary ribbed head and valve chamber. The hot water rises directly from the centre of the top of the cylinder-head by the pipe C, discharging at the top of the copper cylinder DD, while the circulation is maintained by the descending water passing out at the bottom of the copper reservoir by the pipe E through a copper coil which is shown in plan at F. The circulation through one cylinder is entirely separate from that in the other, and complete in itself, both having, of course, a common reservoir in the copper cylinder DD, the level of water in which is shown by means of a water-gauge H.

It is interesting to notice when the engine starts how a warm layer can be felt by putting the hand on the top of the copper cylinder DD, while all the rest of the system remains quite cold, and how, as the engine continues to work, the zone of heat travels downwards, showing how the hot water rises immediately and remains on the top, and indicating the perfect nature of the circulation. It was on a large car where the author first saw a similar system of circulation employed by Mr. Estcourt with most satisfactory results. In view of all the trouble with cars in which pumps are used, as they generally are, it seems a pity that circulation by means of gravity cannot always be employed.

Fig. 1.

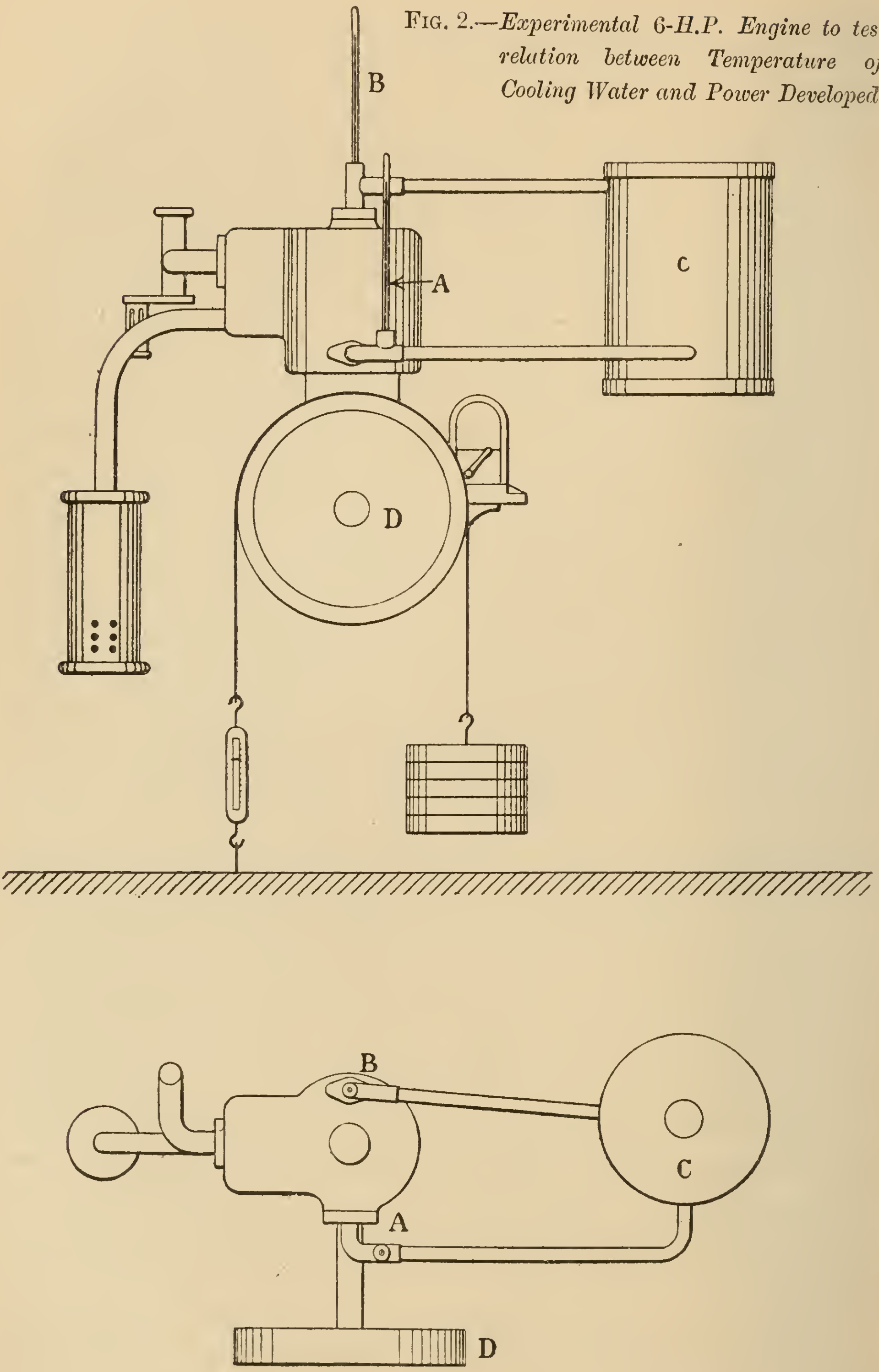
Diagrammatic Sketch of Water-Cooling Arrangement in Voiturette.



Both with the tricycle mentioned and with the above voiturette the water on a hot day during a long run is for considerable periods at a time on the boil, without the power in any way appearing to appreciably diminish; whereas, on the other hand, he has been on larger cars where, owing to the defective working of the pump, the water was not circulating properly, and a considerable amount of steam was being formed. In the latter cases the power fell off in a very serious manner, although the engine never actually stopped, as has been seen with air-cooled motors. It is clear, on a little consideration, that the rate at which water is boiling off, and not the actual fact that water is in contact with the cylinder walls, must be largely a measure of internal heat of the cylinder. On the other hand, amongst those who are accustomed to drive motor cars, there is generally a feeling that the engines work best at a certain temperature somewhere between that at which the water boils off, and the cold state in which the engine actually starts. The author has not been able to find that there exist any actual data upon this subject, and it seemed to be a sufficiently important matter to be worth making some experiments upon. He has, therefore, with the assistance of Mr. Gill, B.Sc., engineering student of the University College of Liverpool, experimented upon the 6-H.P. engine represented in Fig. 2 (page 790). This engine, which has magnetic electric ignition, was fitted with two thermometers, A measuring the water at entrance and B that at exit. C is a tank which was used when the water was allowed to remain at boiling point, but otherwise the two pipes were connected with the mains, and the water at exit kept at the temperature required by allowing a sufficiently rapid flow of water through the cylinder-jacket. D is the flywheel upon which a dynamometer brake acts, so that the power can be accurately tested. A series of five trials were made, four with the water at different temperatures, and the fifth with glycerine circulating in the cylinder-jacket and tank instead of water, in order to obtain a higher boiling point and a higher temperature of the cooling liquid.

The general result of these trials is given in the following Table and plotted in Fig. 3 (page 792), in which the ordinates

Fig. 2.—*Experimental 6-H.P. Engine to test relation between Temperature of Cooling Water and Power Developed.*



represent brake horse-power (which it will be seen under the best circumstances never exceeded about $4\frac{3}{4}$), whereas the abscissæ represent the temperature of the water at exit. The two series of boiling-off experiments have been kept separate from the other three, but the plotted results indicate the same general result:—

Summary of Tests.

Trial No.	Temperature at Entry.	Temperature at Exit.	B.H.P.	Revs.
	F.°	F.°		
1	66·2	77·0	4·775	1086
2	64·4	131·0	4·47	1084
3	64·4	212·0	3·97	903
4	212·0	212·0	4·07	925
5	253·4	253·4	3·94	906

In experiments 1, 2, and 3, the water was running through.

In experiment 3 only a small quantity was allowed to flow, as it was completely evaporated.

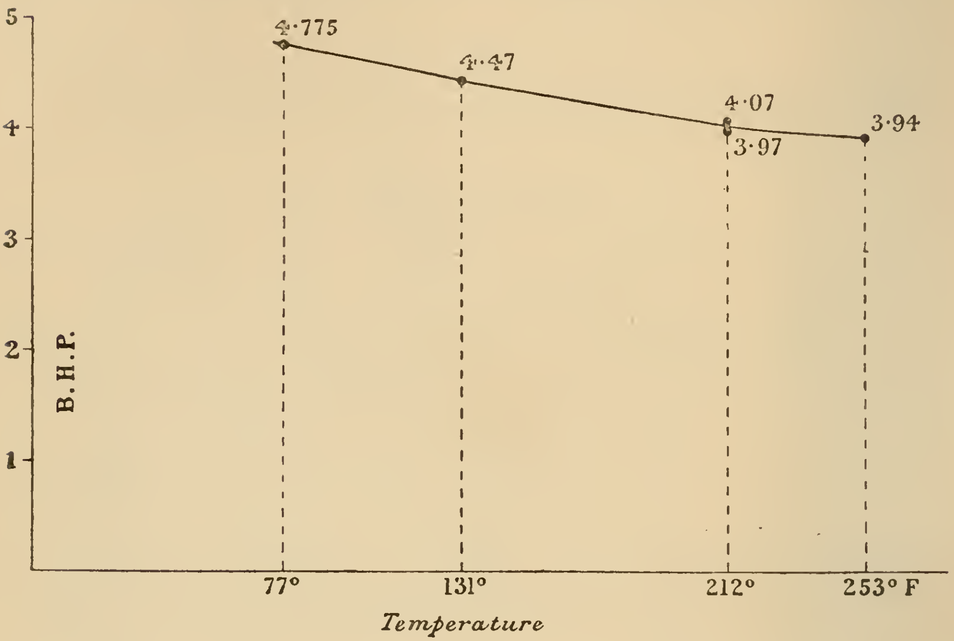
Nos. 4 and 5 were boiling-off experiments.

In No. 5 Glycerine was used.

The general nature of these experiments is immediately obvious, and indicates a falling off in brake horse-power as the temperature rises, the brake horse-power between the two extremes of temperature having fallen from 4·775 to 3·94, a diminution of about 17 per cent.

Each series of experiments represents roughly speaking about ten observations, which were conducted as carefully as possible; but, at the same time, the difficulties of maintaining uniformly the temperature and speed of the engine were sufficiently great to make it undesirable to attempt to produce any mathematical statement from these results; further and more elaborate experiments will be required of temperature taken in conjunction with the actual

Fig. 3.—*Showing relation between Temperature of Cooling Water and B.H.P.*



quantity of water used, before any definite conclusion can be arrived at on this subject. It is interesting to note that Mr. Dugald Clerk, in reply to a letter from the author asking for information, appears to have obtained with a slow-running gas-engine slightly greater efficiency at the higher temperatures; but, of course, the foregoing experiments only deal with actual power, and not with efficiency.

The author has not attempted to discuss the actual cause or causes of the falling off in power as the temperature of the cylinder rises. Whether this is due to lubrication difficulties or thinning of the cylinder lubricant to a point which allows the piston rings to leak, or whether due to heating of incoming charge and consequent weakening of the mixture, would afford matter for an interesting discussion.

The advances in the construction of these high-speed, internal-combustion engines, and the rapidly increasing power which is being evolved from them warrants their careful study. Thus in the recent Paris-Berlin race there were several engines upon light motor vehicles capable of developing more than 50 H.P., with in one case at least a weight of not more than 10 lbs. per horse-power. When it is remembered that this is not merely the equivalent of the steam-engine, but of the engine and boiler, it will no doubt be admitted that any of the points, such as the cooling of the cylinders, which is an essential feature of the problem, is worthy of the attention of this Congress.

The Paper is illustrated by 3 Figs. in the letterpress.

Discussion.

The Chairman said that Professor Hele-Shaw had brought before them a question which was of very great importance at the present time. Before asking them to discuss his Paper, he would call upon them to pass a hearty vote of thanks to the author for the trouble he had taken in coming there that day to read his communication.

Mr. Bryan Donkin, Vice-Chairman, asked whether Professor Hele-Shaw had taken the quantity as well as the rise in temperature of the cooling-jacket water, so as to get the total number of thermal units. Some further experiments on this point would be desirable.

Herr R. Diesel said that the great number of very exact experiments, which he had made, confirmed the main fact told by Professor Hele-Shaw, namely, that the power of internal-combustion motors decreased very rapidly with the increase of the temperature of walls.

Mr. Blackwood Murray thought it would be interesting if Professor Hele-Shaw would inform them by what amount the torque would diminish with the rise of temperature. His firm's experience

(Mr. Blackwood Murray.)

had been that, with engines running at the moderate speed of 500 to 700 revolutions, there was a slow increase from 60° F. up to about 100°, and then on to the boiling point the torque was almost constant. These engines were fitted with governors. Again, the amount of water-jacketing on the cylinder had a very important bearing on the subject. With engines partially water-cooled, the body of the cylinder was usually at a much higher temperature than 212°, and the lubrication of the cylinder in such cases was very difficult; the torque was consequently much decreased. He would be obliged if Professor Hele-Shaw would give the torque at the various temperatures.

Professor Hele-Shaw asked what was the horse-power of the engine referred to.

Mr. Murray said the horse-power was from 7 to 8 horse-power, the two cylinders being 4 inches diameter and 7 inches stroke.

Mr. Bryan Donkin enquired what was the percentage of surface jacketed of the total internal area.

Mr. Murray replied that the whole travel of the piston was water-jacketed, and the whole of the valve chamber also.

Mr. Dugald Clerk had many years ago made some experiments on the effect of temperature upon the power produced by gas-engines. The first experiment was with one of his own engines, the old Clerk type in which the cylinder was 9 inches diameter and the stroke 24 inches. The whole of the cylinder was water-jacketed. Going from ordinary temperature, 60° F. up to the boiling point, he found a steady increase of efficiency with a slight decrease of power, with an increased economy.

In a letter he had written to Professor Hele-Shaw he thought the Professor was enquiring as to heat efficiency, not power. There was a drop in power, but an improvement in economy up to a certain point. The reason of that was fairly evident. In a gas-engine or oil-engine the power depended upon the weight of the charge within the cylinders, when the stroke was complete. In the case of a charge having double the absolute temperature of another charge, there was only half the weight of material present; the result was an engine which gave less power, but a greater economy might be obtained. In the small motors which were used in the motor trials that week, it was very difficult to reason in exactly the same way as with a large gas-engine cylinder using slow speeds. In Fig. 1 (page 788) the cylinder was cooled by radiated ribs and air contact, and the caps and cylinder covers were alone water-cooled. In that engine the temperature of the cylinder and the temperature of the piston, which determined the temperature of the charge, would be very different from the temperature of the water leaving the cylinder head. In the same way, in Fig. 2 (page 790), although a water-jacket included practically the whole stroke of the piston, yet the piston itself projected into a part of the cylinder, which was not water-jacketed, and the lower part got very hot. The efficiency of an engine with increasing water temperature improved up to a certain point, and then fell off again. Experiments with the small air-cooled motors showed a lower efficiency, because the temperatures of the cylinders were somewhat in the neighbourhood of 400° C., which was over-doing it. When the temperatures were so high as that, the efficiency dropped as well as the power: the problem was rather complex, and one had to consider carefully whether power or efficiency was being dealt with; the power invariably dropped. He thought there was no doubt that engineers accustomed to gas-engines had always known and felt that up to a certain point the heating efficiency increased, and his own experiments showed that it increased up to about boiling point.

The Chairman, before requesting Professor Hele-Shaw to reply, would like to ask two questions with regard to Fig. 1 (page 788). He observed there that the pipes C were carried very nearly to the top of cylinder DD. Were they really carried so near as there shown, because, if there was any loss of water, that would prevent any circulation taking place. He did not know whether any provision

(The Chairman.)

had been made for that contingency. The other point was whether the cylinder DD was completely closed, or whether there was an escape valve for any vapour formed.

Professor HELE-SHAW in reply, said, in answer to the question of Mr. Donkin (page 793), he did not measure the quantity of water passing, and did not profess to have dealt with the subject of efficiency as measured by the heat carried off by the water. The temperature of the outcoming water was just a rough indication of the heat of the cylinders. He was very pleased to see that the general results of his experiments were accepted by the various gentlemen who had joined in the discussion, as agreeing with their own experience. He was glad they had had amongst them Herr Diesel, who was so well known and had done so much in the direction of internal-combustion engines, and apparently his experience coincided with what he himself had found on a small scale.

Mr. Blackwood Murray had asked about the torque. The torque increased slightly up to about 135° F., and then fell off. In regard to the remarks of Mr. Dugald Clerk, it was only a question of power that he had there considered, and not a question of efficiency. Driving motor cars was a very expensive matter, and a few ounces more or less of petrol was nothing, as petrol cost about $\frac{1}{2}d.$ a mile and tyres cost probably about $2d.$ One was more anxious to climb a hill quickly than to climb it cheaply. The question into which he had entered was merely one of power. In answer to the Chairman he would say that the tank appeared to act almost entirely in the same way as the Thornycroft boiler, in which the tubes entered above the water line. The water would stand half way down in the gauge, and yet circulated freely above that line and poured out of the top of the rising pipes. The body of water coming out of these pipes at the top was, he thought, partly carried up by the small quantity of steam which had been formed. Finally he assured the Meeting that he had never ventured to close the top of the tank, and would be sorry to do so.

TRIALS OF STEAM TURBINES FOR DRIVING DYNAMOS.

By the Honourable CHARLES A. PARSONS, F.R.S.,
and Mr. G. GERALD STONEY, of Newcastle-on-Tyne.

A description of the earlier forms of Steam Turbines was given in a Paper read before the Institution of Mechanical Engineers in 1888,* and since that date considerable improvements have been made in their design and construction, which have led to a general diminution in steam consumption, and, in the case of large condensing turbines, to some very remarkable results in steam economy. It is hoped that a short description of the turbines, and of the results obtained, may be not without interest at the present time.

Prior to 1890 all steam turbines had been of the non-condensing type, and of comparatively small size, and the results then obtained had not reached that degree of economy which was believed to be possible with steam turbines under practical working conditions.

The next step in advance was the construction of an experimental steam turbine of 200 H.P. in 1892. It was coupled to a 100-kw. alternator, and supplied with moderately superheated steam at 100 lbs. pressure per square inch. When tested by Professor J. A. Ewing, F.R.S., it was found to consume 27 lbs. steam per kw.-hour, thus rivalling the performances of the best compound condensing reciprocating engines. This result placed the steam turbine amongst the most economical means of obtaining electrical energy from steam, and led to its adoption in the lighting stations of Newcastle, Scarborough, Cambridge, and other places.

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* Proceedings 1888, page 480.

About two years later considerable alterations of design and workmanship were introduced; a single-flow type of parallel-flow turbine having been adopted instead of the original double-flow with right and left-handed turbines on each side of the steam inlet, the second set of turbines were replaced by rotating steam balance pistons, and the steam passed in one direction parallel to the shaft. This alteration materially improved the economy and reduced the amount of skilled labour required. The form and construction of the vanes or blades was perfected and strengthened, and many minor improvements, conducive to economy, were made, so that, even in the smaller sizes, a fair degree of efficiency has been obtained, as is instanced by the result of 28·8 lbs. of steam per kw.-hour, or about 17 lbs. per I.H.P., for a 24-kw. steam turbine plant without superheat.

TABLE 1.

Test of 24-kw. Turbo Dynamo for Messrs. Spillers and Bakers, Newcastle-on-Tyne.

Pressure of Steam above Atmosphere at Stop Valve.	Superheat at Stop Valve.	Vacuum in the Turbine Cylinder. Bar. = 30″.	Revs. per minute.	Load.	Steam used.	
Lbs. per sq. inch.	F.°	Inches of Mercury.		Kws.	Lbs. per hour.	Lbs. per kw.-hour
80	0	28·8	4,900	24·7	712	28·8
77	0	29·0	4,630	11·8	400	33·9
74	0	29·1	4,570	5·15	235	45·6
78	0	26·0	4,900	23·8	798	33·5
79	0	0	4,780	19·7	1,350	68·5

The increase of efficiency with better vacuum is well shown here. With 28·8 inches vacuum, this is about 4·7 lbs., or 16 per cent., better than with 26 inches vacuum.

A 50-kw. steam turbine alternator for the Corporation of Blackpool showed a consumption of 28 lbs. per kw.-hour at full load without superheat.

TABLE 2.

50-kw. Steam Alternator for the Blackpool Corporation.

Pressure of Steam above Atmosphere at Stop Valve.	Superheat at Stop Valve.	Vacuum in the Turbine Cylinder. Bar. = 30″.	Revs. per minute.	Load.	Steam used.	
Lbs. per sq. inch.	F.°	Inches of Mercury.		Kws.	Lbs. per hour.	Lbs. per kw.-hour
126	0	28·0	5,044	52·7	1,480	28·0
132	0	28·5	4,880	0	320	—

Two 100-kw. turbo dynamos for traction purposes gave a consumption of 26·4 lbs. per kw.-hour without superheat.

TABLE 3.

100-kw. Turbo Dynamo for Traction Work,
for the Corporation of Blackpool.

Pressure of Steam above Atmosphere at Stop Valve.	Superheat at Stop Valve.	Vacuum in the Turbine Cylinder. Bar. = 30″.	Revs. per minute.	Load.	Steam used.	
Lbs. per sq. inch.	F.°	Inches of Mercury.		Kws.	Lbs. per hour.	Lbs. per kw.-hour
127	0	27·0	4,800	108·45	2,910	26·8
127	0	28·1	4,600	51·35	1,534	29·9
127	0	28·4	4,450	0	300	—

Two 100-kw. continuous current turbo dynamos, constructed for the West Bromwich Electric Light Station, gave a consumption on official trial of 24½ lbs. per kw. with the moderate superheat of 60° F.

TABLE 4.

Two 100-kw. Continuous Current Turbo Dynamos,
for West Bromwich Electric Lighting Station.

Pressure of Steam above Atmosphere at Stop Valve.	Superheat at Stop Valve.	Vacuum in the Turbine Cylinder. Bar. = 30″.	Revs. per minute.	Load.	Steam used.	
Lbs. per sq. inch.	F.°	Inches of Mercury.		Kws.	Lbs. per hour.	Lbs. per kw.-hour
129	54	27·8	3,500	123	3,144	25·5
134	64	27·7	3,520	122	2,913	23·8

Two 100-kw. continuous current turbo dynamos were constructed for the Winwick Asylum, and although the power required to drive the air and circulating pumps was included, a consumption of steam of 25 lbs. per kw. was obtained.

TABLE 5.

Two 100-kw. Continuous Current Turbo Dynamos, combined with condenser and pumps for the Winwick Asylum.

Pressure of Steam above Atmosphere at Stop Valve.	Superheat at Stop Valve.	Vacuum in the Turbine Cylinder. Bar. = 30″.	Revs. per minute.	Load.	Steam used.	
Lbs. per sq. inch.	F.°	Inches of Mercury.		Kws.	Lbs. per hour.	Lbs. per kw.-hour
100	84	28·8	3,640	119	2,886	24·3
91	69	27·6	3,685	121	3,069	25·3
93	62	27·6	3,500	80	2,282	28·4
97	28	27·8	3,200	42	1,525	36·0

Note.—The first test applies to the first machine; the others to the second when the cooling pond was considerably warmer.

Two 200-kw. continuous current turbo dynamos for the Blackpool Corporation for supplying power to the tramways showed a consumption of steam of only 22 lbs. per kw.-hour, the superheat in this case being 60° F.

TABLE 6.

Two 200-kw. Continuous Current Traction Turbo Dynamos, for the Corporation of Blackpool.

Pressure of Steam above Atmosphere at Stop Valve.	Superheat at Stop Valve.	Vacuum in the Turbine Cylinder. Bar. = 30″.	Revs. per minute.	Load.	Steam used.	
Lbs. per sq. inch.	F.°	Inches of Mercury.		Kws.	Lbs. per hour.	Lbs. per kw.-hour
129	58	27·6	3,045	226	4,975	22·0
122	60	28·4	3,010	232	5,079	21·9
119	0	26·9	3,000	204	4,943	24·2
130	0	28·0	3,010	0	950	—

An instructive series of tests has been made on various 500-kw. Turbo Alternators. These are summarised in the following Table :—

TABLE 7.

Various 500-kw. Turbo Alternators.

Pressure of Steam above Atmosphere at Stop Valve.	Superheat at Stop Valve.	Vacuum in the Turbine Cylinder. Bar. = 30″.	Revs. per minute.	Load.	Steam used.	
Scarborough Electrical Supply Co.						
Lbs. per sq. inch.	F.°	Inches of Mercury.		Kws.	Lbs. per hour.	Lbs. per kw.-hour
126	0	26·75	2,400	529	22·7	12,023
128	0	27·7	,,	258	26·4	6,812
164	0	28·1	2,600	0	—	1,477
Cheltenham Corporation.						
130	0	26·7	3,000	553	21·7	12,000
130	0	26·6	,,	278	26·2	7,280
133	0	24·0	,,	553	23·6	13,060
130	0	,,	,,	453	24·8	11,250
135	0	,,	,,	276	29·65	8,175
Blackpool Corporation.						
146	70	27·1	2,500	515	21·35	11,000
150	0	27·0	,,	502	23·1	11,600
135	0	27·3	,,	497	24·0	11,953
133	66	27·3	,,	507	21·1	10,693
152	0	29·0	,,	0	—	1,500
160	0	23·6	,,	0	—	2,530
156	5	28·9	,,	0	—	1,465

It will be noted from the above results that the improvement in steam consumption resulting from a superheat of 50° F. is about 8 per cent., and from 100° F. it averages about 12 per cent. ; also that for every 1 inch of vacuum above 25 inches or 26 inches, the consumption falls about 4 per cent.

On this basis the steam consumption with about 140 lbs. steam pressure at the stop valve and no superheat under various conditions of load and vacuum has been prepared for a 500-kw. plant.

TABLE 8.

(Based on results shown in Table 7.)

Consumption of 500-*kw. Turbo Alternators running at* 2,500 *revolutions with* 140 *lbs. steam pressure at the stop valve and no superheat.*

Vacuum constant from full load to no load.	Consumption per kw.-hour.			
Inches of Mercury.	Full load.	½	¼	No load.
29	—	—	—	1,500
28	22·2	25·6	32·4	1,700
27	23·1	26·9	34·5	1,900
26	24·0	28·2	36·6	2,100
25	25·1	29·7	39·9	2,300
24	26·2	31·2	41·2	2,500
23	27·5	32·9	44·8	2,700
22	28·9	34·7	46·3	2,900
Vacuum rising from full load to no load.	**Consumption per kw.-hour.**			
Inches of Mercury.	**Full load.**	**½**	**¼**	**No load.**
From 28 to 29½	22·2	25·0	30·5	1,400
„ 27 to 29	23·1	26·1	32·0	1,500
„ 26 to 28½	24·0	27·2	33·6	1,600
„ 25 to 28	25·1	28·5	35·2	1,700
„ 24 to 27½	26·2	28·9	37·0	1,800
„ 23 to 27	27·5	31·3	38·9	1,900
„ 22 to 26½	28·9	33·0	41·2	2,000

Barometer = 30″ Mercury.

It will be noted that in steam turbines the steam consumption closely follows a right line law, or is proportional to the load *plus* a constant quantity which represents the consumption of steam at no load.

In connection with superheated steam, it may be mentioned that, as there is no internal lubrication of the turbines, none of the usual difficulties which occur with reciprocating engines are met with in its employment.

Also in steam turbines the absence of internal lubrication renders the exhaust steam absolutely free from oil, so that the water from the hot well can be returned to the boilers direct without oil filters.

Special tests * have been made from time to time on turbine engines to verify the statement that no increase in steam consumption occurs with the age of the plant under fair wear and tear.

A long and exhaustive series of tests was made in January 1900 by Mr. W. H. Lindley and Professors Schröter and Weber, on behalf of the city of Elberfeld in Germany, on one of two 1,000-kw. turbo alternators built at Heaton Works for that city. The turbo alternators were constructed to give 1,250 kws. at 4,000 volts 50 periodicity, the alternators being four-pole running at 1,500 revolutions per minute, and directly coupled to the turbines. The expansion of the steam was carried cut in two cylinders, a high pressure and a low pressure, the steam being expanded down to a little below the atmosphere in the first, and from that to the vacuum of the condenser in the second. The following description of the test is extracted from Messrs. Lindley, Schröter and Weber's report to the city of Elberfeld :—

> "The tests were made upon the first of the two 1,000-kw. steam turbines to be delivered by the firm.
>
> The turbo alternator was erected in the large testing house of the firm upon a wooden framework made to replace the foundation in the permanent installation which will be four mètres high, in such a manner that the turbine, piping, condenser, air-pump, etc., in fact occupied exactly the same relative position as they will in their final arrangement. The accompanying reproduction, Plate 158,

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* Such as that made at the Cambridge Electrical Supply Station on a 500-kw. Turbo Alternator by Professor Ewing.

illustrates the installation. The steam was taken from the following boilers, and at the normal pressure of about ten atmospheres absolute:—

One Babcock and Wilcox boiler of about 227 m^2 heating surface.
Two Marine Boilers, each of about 550 ,, ,, ,,
One Locomotive Boiler of 67 ,, ,, ,,

A Babcock and Wilcox superheater, with independent firing, was introduced into the main steam-pipe.

It should here be mentioned that the boilers in the works had to be used, as it was manifestly impossible to procure an entirely new boiler plant for the purpose of testing a machine of such great power. The boilers having been in use at the works for a long time, were not quite tight, and their condition did not permit of an exact measurement of the feed-water consumption when the turbine was running at full load.

As the results of the preliminary tests had shown that it was permissible to determine the steam consumption by a direct measurement of the steam condensed in the surface condenser, *i.e.*, of the discharge of the air pump, it was decided to adopt this method. Thus it was possible simply to take the steam for the tests from the various boilers and mains already existing in the works.

For testing at half load, however, the Babcock and Wilcox boiler was available, and being in thoroughly good order, permitted of an absolutely trustworthy measurement of the feed-water consumption at that load.

In order to fix the relation between the steam condenser or discharge of the air pump and the feed-water consumption, a trial of ½ load was made with the boiler alone, during which, both feed-water and air-pump discharge were carefully measured during a fixed period. For this purpose the steam main was cut off by blank flanges from all other connections, except that which led directly from the boiler through the superheater to the steam turbine.

It should be at once observed that, in accordance with results previously obtained by the preliminary tests, this trial revealed a very slight difference between feed water and steam condensed. This difference was due to trifling leakages in the steam main. The determination of steam consumption from the measurement of air-pump discharge was therefore in the present case proved to be trustworthy.

The cooling water for the condenser was taken from a large cooling water pond. The delivery was effected by means of a helical pump driven by an electric motor. The pump forced the water through the tubes of the surface condenser in precisely the same way as will be the case in the station at Elberfeld, where the centrifugal pumps driven by electric power are to be used.

The firm had arranged a water resistance for loading the machine, consisting of four electrodes, which were immersed in four iron vessels fitted with water coolers, representing respectively the four graduations of the normal load of the alternator, viz., $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, and full load.

The instruments for electrical observations consisted of a standard wattmeter with the necessary resistance, and a static voltmeter, as well as an ammeter from the laboratory of the Federal Electro-technical Institute in Zurich.

In order to determine the steam consumption from the air-pump discharge, the latter was conveyed through a special pipe into two wrought-iron vessels. A three-way cock was arranged in this pipe in such a way that, at a given signal, the connection with the one vessel could be instantly cut off, and diverted to the other.

The moment of the completion of each filling, and therefore of each change of vessels, was exactly taken by chronometer; moreover, as each vessel was emptied, the temperature of the condensed steam as it flowed from the vessel, and also the temperature of the cooling water, were noted. When testing at the lighter loads—as the filling lasted longer—observations of the cooling water were made at intermediate intervals.

TABLE 9 (*continued on page* 808).—*Abridged Table of Results of Tests of* 1,000-*Kw. Turbo Alternator, for Elberfeld Corporation.*

Load.	Temperature of Steam.	Absolute Steam Pressures.					Temperature.		
		Before the Stop Valve.	In the Steam Chest.	End of the High Pressure Cylinder.	Low Pressure Cylinder.		Condensed Steam.	Cooling Water.	
					Inlet.	Outlet.		Inlet.	Outlet.
	C.°	Kg. per cm².		Cm. of Mercury.			C°.	C.°	C.°
Preliminary Test (Overload)	250	10·10	7·62	45·9	—	4·13	28·5	8·5	28·2
Normal Load	192	10·47	6·70	40·5 =0·551 Kilogrammes per cm.²	38·7 =0·526	3·9 =0·053	28·0	9·2	27·6
Overload	189·5	10·11	7·81	49·0 =0·666 Kilogrammes per cm.²	46·9 =0·638	4·65 =0·063	32·8	10·9	31·6
Three-quarter Load	190	10·76	5·67	33·4 =0·45 Kilogrammes per cm.²	31·7 =0·431	4·0 =0·054	30·3	15·3	30·6
Half Load	209·7	10·40	4·32	26·4 =0·36 Kilogrammes per cm.²	24·4 =0·33	3·4 =0·046	26·2	17·2	29·3
Quarter Load	196·4	10·14	2·78	19·3 =0·26 Kilogrammes per cm.²	17 =0·231	3·7 =0·05	24·8	18·8	27·6
No Load with Excitation	193	10·34	1·115	10·3 =0·140 Kilogrammes per cm.²	7·7 0·105	3·2 =0·043	—	—	—
No Load without Excitation	194·5	10·49	0·599	7·34 =0·100 Kilogrammes per cm.²	5·33 =0·072	2·68 =0·037	—	—	—

TABLE 9 (*concluded*).—*Abridged Table of Results of Tests of* 1,000-*Kw. Turbo Alternator, for Elberfeld Corporation.*

Load.	Total quantity of condensed Steam.	Duration of Filling.	Average Output of Dynamo.	Useful Work done by Dynamo.	Steam Consumption per Kw.-hour.		Revs.	Excitation.		Average Potential.
	Lbs.	Mins.	Kw.	Kw.-hours.	Lbs.	Kgs.		Volts.	Ampères.	Volts.
Preliminary Test (Overload)	15,000	42′ 11″	1172·7	823·22	18·22	8·26	1493	129·8	100·4	4162
Normal Load	37,500	112′ 17″	994·8	1860·9	20·15	9·14	1461	95	121	3995
Overload	25,000	64′ 51·5″	1190·1	1286·4	19·43	8·81	1486·6	95·9	118·5	4001
Three-quarter Load	37,500	134′ 56·5″	745·35	1681·02	22·31	10·12	1469·9	93	118·13	3994
Half Load	50,000	238′ 54·5″	498·7	1985·80	25·2	11·42	1473	96·6	115·5	4013
Quarter Load	11,500	82′ 53″	246·5	340·77	33·76	15·31	1485	95·8	111·7	4001
No Load with Excitation	2,500	36′ 54″	—	—	—	—	1488·3	94·8	110·4	3968
			i.e. 4065 lbs. per hour = 1843·9 kgs.							
No Load without Excitation	1,500	34′ 31″	—	—	—	—	1504·5	—	—	—
			i.e. 2607 lbs. per hour = 1182·5 kgs.							

TABLE 10.

Results of the Tests showing how the Steam Consumption depends on the Output of the Turbo Alternator.

Amount of load.	Exact value of output.	Steam Consumption per kw.-hour.		Steam Consumption in one hour.
	Kw.	Lbs.	Kgs.	Kgs.
Preliminary trial . . .	1172·7	18·22	8·26	9,689
Overload	1190·1	19·43	8·81	10,485
Normal load	994·8	20·15	9·14	9,092
Three-quarter load . . .	745·3	22·31	10·12	7,542
Half load	498·7	25·20	11·42	5,695
Quarter load	246·5	33·76	15·31	3,774
No load with alternator excited .	0	—	—	1,844
No load without excitation . .	0	--	—	1,183

A direct comparison of these results is not possible, because the measurements have not been made at one and the same steam pressure, and above all, not with exactly the same amount of superheating.

Therefore on the basis of the results of the measurements the steam consumption has been calculated at the average superheating recorded in the observations, viz., 14·3° C., corresponding to a steam temperature of 197·3° C. These corrected results will be found in column 11 of the following Table (page 811).

Further, to enable a comparison to be made with the steam consumption of reciprocating engines, working with saturated steam, the equivalent steam consumption, calculated as saturated steam at 11 atmospheres, is given in column 12 of the same Table.

TABLE 11.—*Based on Results*

Load.	Average observed Steam Pressure. Absolute.	Corresponding Temperature of Saturated Steam.	Average observed Temperature of Superheated Steam at Inlet Valve.	Superheating (Col. 4—Col. 3).	Observed Steam Consumption per kilowatt-hour.
(1)	(2)	(3)	(4)	(5)	(6)
Kilowatts.	Kgs. per cm².	C.°	C.°	C.°	Kgs.
1190·1	10·11	179·3	189·5	10·2	8·81
994·8	10·47	180·9	192·0	11·1	9·14
745·3	10·76	182·0	190·0	8·0	10·12
498·7	10·40	180·6	209·7	29·1	11·42
246·5	10·14	179·4	196·4	17·0	15·31
No load with excitation.	10·34	180·3	193·0	13·3	per hour. 1844
No load without excitation.	10·49	181·0	194·5	13·5	1183

of Tables 9 *and* 10 (*pages* 807–809).

Total heat contained in 1 kilogramme of steam at observed steam pressure.		Measured Consumption of Heat per kilowatt-hour (Col. 8 × Col. 6).	Corresponding Consumption of Saturated Steam per kilowatt-hour (Col. 9 ÷ Col. 7).	Corresponding Consumption of Steam at 11 kgs. absolute and at 14·3° superheating (1 kg. of steam = 669·2 cal.).	Corresponding Consumption of Saturated Steam at 11 atms. absolute (1 kg. of steam = 662·3 cal.).
In Saturated condition.	In Superheated condition.				
(7)	(8)	(9)	(10)	(11)	(12)
Calories.		Calories.	Kgs.	Kgs.	Kgs.
661·1	666·0	5,867	8·87	**8·76**	8·86
661·7	667·0	6,096	9·21	**9·11**	9·20
662·0	665·8	6,738	10·18	**10·07**	10·17
661·6	675·6	7,715	11·66	**11·53**	11·66
661·2	669·4	10,248	15·50	**15·31**	15·47
		per hour.	per hour.	per hour.	per hour.
661·5	667·8	1,231,423	1861	**1840**	1859
661·7	668·2	790,481	1194	**1181**	1194

For the following outputs in round numbers the steam consumption per hour is as shown:—

Output.	Steam Consumption per hour.	Steam Consumption per kw.-hour.
Kw.	Kgs.	Kgs.
1,250	10,786	8·63
1,000	9,189	9·19
750	7,496	9·99
500	5,707	11·41
250	3,821	15·28

On the second plant, tests were made to determine the advantages of superheating, and also the effect of varying the vacuum.

Pressure Stop Valve.	Superheat.	Vacuum. Bar. = 30″.	Kilowatts.	Steam per Kilowatt-hour.
Lbs. per sq. in.	C.°	Inches of Mercury.		Lbs.
157·5	0	26·97	1,010	23·08
153	0	24·45	1,041	25·25
125	0	27·10	1,022	20·47

These show a gain of about 12 per cent. with 55° C. superheat, and that every inch of vacuum improves the consumption about 4 per cent.

In non-condensing plants also many tests have been made, but, as will be expected, the steam turbine compares rather more favourably with the reciprocating engine in condensing types. In a 100-kw. size a consumption of 39 lbs. per kw.-hour has been attained, and in a 250-kw. turbo dynamo 33 lbs. per kw.-hour, both with about 130 lbs. steam pressure and no superheat.

In larger sizes of 1,500 kw., with 200 lbs. steam pressure and 150° F. superheat, a consumption of 28½ lbs. per kw.-hour non-condensing has been guaranteed, and is expected to be easily attained, if not surpassed.

The Paper is illustrated by Plate 158.

Discussion.

The Chairman thought there were very few present who had not followed with great interest the progress which has been made by Mr. Parsons in the development of his steam turbine. Mr. Parsons had bestowed on the perfection of this engine an enormous amount of patient investigation and high mechanical skill, and in thanking him and Mr. Stoney for the Paper that had been read in abstract he was sure they would all wish to convey to Mr. Parsons their congratulations on the success which he had attained.

Professor Schröter, of Munich, said that, as a member of the special committee mentioned by Mr. Stoney, he had had the good fortune to take part in the trials of the 1,000-kw. Parsons turbine made at Heaton Works, and from personal experience could therefore corroborate all the statements of Mr. Stoney; he would only make the additional remark that they were very much struck by the excellent economical results of this remarkable engine. The report presented by Messrs. Lindley, Weber, and himself upon these trials had been published, as also would be the report upon similar trials, made with the same turbine six months after its erection in the electric supply station at Elberfeld; the results were even better than at Newcastle, and were due to a slightly greater superheat. One of the most interesting features of these later trials was the comparison with a Sulzer engine with Brown-Boveri alternator of 1,000 kw., running in the same engine-house; the behaviour of the two types of steam-driven motors differed in so far as the steam consumption of the turbines, other things being equal, decreased constantly with increasing loads, whereas the piston engine showed the highest consumption with maximum load. The reason was obvious. The theoretical condition for maximum economy was, that expansion must be carried down to the condenser pressure; the piston engine differed from that ideal case, and more and more with increasing load—and consequently increasing cut-off, whereas in the turbine the thermal pressure of the expanding steam was always equal to the condenser pressure, but with decreasing load the admission steam was throttled more and more. Similarly with light loads, the piston engine more nearly approached the theoretical conditions, and with heavy loads it was the turbine—somewhere near the normal load the two met. This point would be clearly shown in their report upon the Elberfeld trials.

Both types of steam motors showed an increasing economy with superheat, although from different reasons; and it would be an interesting addition to Messrs. Parsons and Stoney's valuable Paper, if some details could be given about the ratio of increase of the economy with increasing superheat. He knew that experiments in this line had been made. In concluding, he wished to congratulate English engineers, and especially Mr. Parsons, on the very great success of his infatigable work in bringing this new rival of the piston steam-engine to its present state of perfection.

The Chairman believed that, when these turbines were put down in Elberfeld, there was some little doubt expressed as to whether there would be a difficulty in running them synchronously with other engines. He believed, however, that the results had been quite satisfactory, but perhaps Professor Schröter could speak on this point.

Professor Schröter replied that from the first moment of running these engines in parallel with other engines they had not given the least difficulty. It was remarkable how easily they ran parallel with each other as well as with ordinary steam piston-engines, and it was a matter of great satisfaction to the city of Elberfeld to see how easily the parallel running was made.

Professor William Ripper said that one of the great advantages of the Congress was that it provided an opportunity of meeting their Continental colleagues, whose experience was of such interest. As one who had had a fair amount of experience with superheat, it had been a puzzle to him to know how it was that high superheat, which had been productive of such extremely good results economically in the ordinary piston-engine, was not used in the turbine. The temperatures mentioned as having been tried were 50° to 80° F. Continental engineers knew that superheat of 350° F. was used in all the Schmidt type of engines, and he thought high superheat would be likely to show even better results than any hitherto obtained with the turbine. They were told that the terminal pressure of the turbine was the same as the pressure in the condenser. That was a very significant fact. At Charlottenburg he had seen some elaborate experiments being made on a sulphur-dioxide engine, so applied as to obtain work out of the heat between the temperature of the terminal pressure in the engine cylinder and the temperature of the condenser, and it was supposed that it would be worth while having an intermediate engine between the steam-engine itself and the condenser to use this heat. It seemed to him that the Parsons' steam turbine gave an excellent means of using that particular part of the heat, which so far had been thrown away. He thought this use of the turbine had not been sufficiently emphasised. The turbine lent itself to the use of high superheat more easily than any other class of engine. One of the difficulties about the use of high superheat was that of unequal expansion in the cylinder, but the turbine lent itself to the application of high superheat without the slightest fear of any trouble due to unequal expansion of the casting.

Mr. Bryan Donkin, Vice-Chairman, said it would be very interesting to know the economical results between a triple standard piston-engine and the steam turbine.

Professor Schröter was sorry he could not give the figures, as the report to the Corporation of Elberfeld had not yet been received.

Mr. G. Gerald Stoney, in reply, said tests made on turbines which have been running for a long time showed that there was no falling off of economy. With reference to superheat, a small degree of superheat gave about 5 to 6 per cent. extra economy: 50° F. 8 per cent., and 100° F. 12 per cent. No tests had been

(Mr. G. Gerald Stoney.)

made at higher degrees of superheat, but there was no doubt the economy would increase with higher superheats, and would probably reach 20 per cent. with 350° F. There was no difficulty in working with any degree of superheat the superheater would stand. The effect of a good vacuum was felt more in the steam turbine than in an ordinary engine, as it expanded right down to the vacuum of the condenser, which is not possible in an ordinary engine. In relation to the consumptions of ordinary engines and turbines at Elberfeld, where both were installed in the same station and therefore were tested under the same conditions, the consumption of the steam turbines from three-quarter to full load was better than that of the Sulzer triple-expansion engines. There was no difficulty in paralleling alternators driven by turbines, either with themselves or with those driven by other engines. Turbo-alternators were running successfully in parallel with every sort of engine at various stations, and there were no difficulties in paralleling even where, as in the case of Elberfeld, the turbines were running sixteen times as fast as the Sulzer engines.

The Chairman said that Mr. Stoney had added to their indebtedness by the reply which he had given to the discussion, and they were also very much indebted to Professor Schröter for the information he had given.

SOME PARTICULARS OF THE RESULTS OF THE COMPOUND LOCOMOTIVE ON THE BUENOS AIRES GREAT SOUTHERN RAILWAY.

By Mr. R. GOULD, Locomotive, Carriage, and Wagon Superintendent,
Buenos Aires Great Southern Railway, Argentine Republic.

The question of coal consumption of locomotives becomes in countries like the Argentine Republic, which depends entirely on the imported article, a matter of paramount importance, and an endeavour to secure an economy in this respect led to the trial of the compound engine.

The type of engine adopted on the Great Southern Railway was the two-cylinder "Worsdell and Von Borries," as being the simplest arrangement, and interfering least with the duplication of parts of the standard simple engines previously in service. All these engines, both simple and compound, were built by Messrs. Beyer, Peacock and Co., under the instructions of Messrs. Livesey, Son and Henderson, the Company's Consulting Engineers.

The first compound engines ordered were erected in 1889, and the results obtained were so excellent that, with the exception of shunting and local traffic engines, no simple engines (either goods or passenger) have since been ordered.

The engines proved easy to handle, exhibited a high economy in coal and water, and owing to the reduced demand on the boiler, showed less tendency to priming and scale than the original simples; they can run much fuller into gear without lifting the water, and thus haul heavier loads. As an offset against these advantages, the first compounds sometimes showed an inclination to jib after starting, due to the rapidity with which the automatic "Worsdell and Von Borries" starting valve caused compounding to take place, reducing the power by cutting off the live steam from the low-pressure cylinder before (in the case of long and heavy trains) the whole weight was fully taken on the drawbars, or the whole train set in motion. In this valve, Fig. 9, Plate 161, the exhaust steam from the high-pressure cylinder is held in check by a mushroom valve which closes automatically by the action of live steam from the boiler, admitted to a pair of small pistons operating on the back of the large mushroom. With this valve closed, no high-pressure exhaust steam can pass, and the low-pressure cylinder is temporarily fed by a by-pass of live steam from the boiler. The high-pressure exhaust being completely bottled up, compounding takes place very rapidly, as the back-pressure rising forces open the large mushroom and shuts the by-pass. The defect was got over by an improvement made in the Company's Works at Buenos Aires in introducing a hollow spindle in the mushroom valve with an escape passage to the chimney, Fig. 8, the office of the passage being to relieve the H.P. back-pressure to some extent, and so delay compounding. The compound engines fitted with this valve are more powerful in starting than either those fitted with the original valve, or the simple engine. The by-pass admits and maintains the live steam for a longer period in the low-pressure cylinder, so that perhaps three or four revolutions of the wheels take place (more or less according to the weight of the train), and the longest train is well in motion before the back-pressure accumulates sufficiently to close the valve, and compounding takes place.

The effect of the alteration in the intercepting valve was to obviate the tendency to jib previously experienced, and to ensure a certain and easy start, with the maximum power, whilst retaining the automaticity of the valve's action, a most valuable and important feature, putting it out of the power of the driver to work non-compound longer than absolutely necessary, which by some non-automatic systems is possible, and tends to reduce the economy.

This hollow spindle arrangement was found so successful that the intercepting valves of the whole of the compounds—some 109 engines —were so fitted. A detail of this valve is shown on Fig. 8, Plate 161.

The accompanying diagrams show the principal classes of compound engines on the Great Southern Railway, and also the corresponding simple engines for two classes. Figs. 1 and 2, Plate 159, and 4 and 5, Plate 160, compare absolutely. Fig. 7, Plate 161, designed by the author, for working either goods or heavy passenger trains, represents the most modern engines of the Company, whilst Fig. 3, Plate 159, shows an engine of special interest as regards the compound question, in that it was constructed from old engines similar to Fig. 1 at the Company's Works. Increasing weights of trains made it necessary to do something to adapt engines, Fig. 1—of which the Company possessed a large number—to the heavier demand on their power. The boilers of some of the older engines were replaced by new and larger ones carrying higher pressure, the cylinders being at the same time changed for those of increased size, and the engines compounded, the new type being represented in Fig. 3. As tank engines were required at the time, the boilers and cylinders of engines, Fig. 1, of later date than the before-mentioned, which were in good condition, were transferred to new frames and wheels, &c., making the tank engines, Fig. 6. Additional parts necessary to make up complete engines were ordered, and in conjunction with the parts of the engines, Fig. 1, dealt with, enabled two sets of up-to-date engines, of increased power, to be put on the rails, in place of one of somewhat obsolete type, of insufficient power, withdrawn.

The engines, Fig. 3, have proved a great success, being from 25 to 30 per cent. more powerful than the old Class 6 which they supersede, and showing an economy of fuel even better than that of the compounds, Fig. 2.

The tabular statement (page 822) shows the coal and lubricant consumption, and also the comparative cost of repairs for the mileages given. In using this latter it may be useful to note that the average age of engines Fig. 1 is 16 years; Fig. 2, 10 years; Fig. 4, 14 years; and Fig. 5, 11 years. The engines, Figs. 1 and 2, 4 and 5, are duplicate in all respects excepting the compounding, and in making up the cost of repairs, the accounts of which are always kept separate for each engine, a careful selection has been made, so as to eliminate those of the older ones of the non-compound engines in which such heavy items as renewals of tubes and fireboxes, &c., would make the comparison unfair for them. The repair statement includes all repairs, general and intermediate, for the mileages given, and although the comparison may not be perfectly exact, it is the nearest that could be obtained, and is sufficiently accurate to show that at least the compound engines are no more expensive to maintain than the non-compound, whilst the economy of fuel and water is beyond question.

It will be seen from the Table that the engines, Fig. 2, burn 23 per cent. less coal per axle than their compeers, Fig. 1, the loads being practically equal, whilst the engines, Fig. 3, actually show an economy of 37 per cent., but as the latter have hauled heavier trains (which naturally show a greater economy in consumption per axle hauled) some of this economy must be discounted.

In the case of the engines, Figs. 5 and 7, an economy of 14 per cent. over the Fig. 4 is shown, but here again allowance must be made for the fact that the simple engines Fig. 4 hauled more axles. The classes, Figs. 5 and 7, especially the latter, were employed for the heavier passenger trains, whilst the engines on Fig. 4 were almost entirely employed on goods traffic, not being equal to the task of the heavy passenger work at the higher speeds. If it were not for these circumstances, the classes Figs. 5 and 7 would exhibit an economy equal in amount to that of the Figs. 2 and 3.

In the matter of lubricants the simple and compounds show practically no difference.

The absence of heavy grades on the Buenos Aires Great Southern Railway renders it a favourable field for the compound engine, the grades of importance being in one district only, the bulk of the line being practically straight and level. The character of the traffic, with long runs and full trains as a rule, causing an approximation to the fixed load of a stationary engine, is also favourable for the compound system.

In the comparison of the cost of repairs it must not be forgotten that this is as between the simple and compound engine only. The cost of wages in Buenos Aires is at present about 50 per cent. more than in England, and the material, although imported duty free, has to bear several extra charges, such as freight, packing, insurance, &c., that enhances its cost when delivered to the Company's workshops in Buenos Aires.

The consumption statement is made up from the ordinary mileage and consumption sheets for each month of 1900, extracted from the summary in which the different engines and their performance is totaled for each class; all coal and oil used for shunting and light mileage, &c., is included in the train-mileage figure, which, on the Great Southern Railway, bears a larger proportion to that on many railways where a complete service of booked trains is run, the bulk of the goods traffic being by specials in dealing with the wheat, wool and cattle trains, which have to run as soon as made up, the engines being supplied on "the first in first out" principle. The railway is also composed of a large number of branch lines with many junctions, also tending to make the working difficult; the water is of a quality that induces much priming, and the bulk of the road is unballasted except by the earth of the district run through, which in wet weather becomes soft and yielding, tending to increase the tractive effort, and consequently the consumption. All this must be taken into consideration when criticising the figures, which are ordinary averages, no attempt having been made to record the best performance on special runs; the main point is to show the comparison of the performance of the compound and simple engines doing similar work under similar conditions.

The Paper is illustrated by Plates 159 to 161.

APPENDIX.

Consumption of Coal and Lubricants for the year 1900.
Engines, Classes 6, 6A *and* 6B, 7, 7A *and* 10.

	Passenger Engine.			Goods Engine.		
	Simple.	Compound.		Simple.	Compound.	
	Class 6 Fig. 1	Class 6A Fig. 2	Class 6B Fig. 3	Class 7 Fig. 4	Class 7A Fig. 5	Class 10 Fig. 7
Coal consumed per train-mile lbs.	36·00	28·05	29·25	55·68	45·00	40·50
Average weight of trains . tons	162	166	211	624	585	526
Average number of axles per train	25	25·5	32·5	96	90	81
Coal consumed per axle per mile . . . . . lbs.	1·44	1·10	0·9	0·58	0·50	0·50
Lubricant consumed per 100 train-miles . . . lbs.	7·70	6·45	6·28	7·13	7·27	5·96
Lubricants consumed per 100 engine-miles . . . lbs.	6·38	5·96	5·96	5·57	5·96	5·32
Ratio of coal consumed per axle per mile	100	76·4	62·5	100	86·2	86·2

*Cost of Repairs (General and Maintenance).**
Engines, Classes 6, 6A, 7 *and* 7A.

	Passenger Engine.		Goods Engine.	
	Simple.	Compound.	Simple.	Compound.
	Class 6 Fig. 1	Class 6A Fig. 2	Class 7 Fig. 4	Class 7A Fig. 5
Number of engines repaired . .	32	24	22	43
Average cost of repairs per engine per mileage shown . . .	£510	£470	£498	£470
Average number of engine-miles run for above engine repairs . .	51,034	55,865	54,769	55,224
Average number of engine-miles run per annum	23,916	28,920	20,556	25,692

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* The maintenance does not include wages of running-shed fitters, but is for material and spare parts supplied during service.

Discussion.

The CHAIRMAN said that Mr. Gould had given them a very interesting record of facts to which they would be glad to refer in the future. He regretted that the author was not there that day to answer any remarks that might be made. He asked them to accord to Mr. Gould a vote of thanks for his communication.

Mr. MICHAEL LONGRIDGE, in reply to a question put by Mr. Halpin, said it seemed to him that the valve, Fig. 8, Plate 161, was kept in position at the start by two small pistons exposed to the boiler pressure, and that in the meantime steam was admitted from the boiler into the low-pressure cylinder; that was, into the vertical pipe on the drawing. He could not see how the valve was to open against this boiler pressure, when the pressure in the exhaust from the high-pressure cylinder increased.

The CHAIRMAN said the pressure which opened the valve was that of the accumulated exhaust from the high-pressure cylinder.

Mr. LONGRIDGE said he understood that in starting, the boiler pressure was admitted into the low-pressure cylinder, and was consequently on the other side of the valve. How did the exhaust pressure from the high-pressure cylinder open the valve against the boiler pressure admitted to the low-pressure cylinder?

The CHAIRMAN said that, unless the engine was worked differently from those on the Worsdell-von Borries system in use on the North Eastern and other railways, the steam which was supplied from the boiler to the low-pressure cylinder when starting was admitted through a reducing valve, and when the exhaust pressure from the high-pressure cylinder became greater than that of the steam so admitted by the reducing valve, then the large intercepting valve

(The Chairman.)

opened. In the case of the improved design of valve shown in Fig. 8, Plate 161, there was an arrangement admitting of the leakage of some of the exhaust steam from the high-pressure cylinder direct to the chimney, so that on starting the back pressure against the high-pressure piston did not accumulate quite so fast as it did in the original arrangement, Fig. 9.

THE RATING AND TESTING OF ELECTRICAL MACHINERY.

By Mr. GISBERT KAPP, of Berlin.

Electrical engineering enters into so many industries, and has modified the conditions of modern life to so large an extent, that the sale of electrical apparatus has become an important factor in the commerce of every civilised country. To place this commerce on a safe basis, it is however necessary to arrive at a clear understanding as regards the properties of the different articles bought and sold. This necessity becomes the greater the more the international character of the trade in electrical apparatus is developed, and for this reason the subject of this Paper may be considered as specially suited for the consideration of an International Engineering Congress.

At first sight it may perhaps be thought that the determination of the power, efficiency, and other qualities of electric machines is a simple matter. Electric measurements can be made with so great a degree of accuracy that two experts, if they test the same apparatus under the same working conditions independently of each other, must arrive at the same results. Hence if one expert acts for the seller and the other for the buyer of the apparatus, no difference could seemingly arise. Yet it is seen daily that such differences do arise, and the reason for this state of things is that the tests are not made under the same working conditions, and that no general understanding exists as to what shall be tested and how. As an illustration, the case of a tramway motor may be taken. The manufacturer designates it as capable of developing a certain H.P. According to his method of rating this does not mean that the motor is capable of giving off hour after hour and all day long this H.P. It only means that the motor can, in the usual way of working tramways, give off that power whenever it is required. Now as a rule the periods during which this full power is required form only a small fraction of the time during which the motor is in service. In such cases it would obviously be bad economy to put in a motor capable of giving off the full power permanently. Yet in other cases this may be necessary. Thus if the line contain a moderate grade many miles long, it will require larger motors than a line having very stiff but short grades, yet in the former case the maximum H.P. required is less than in the latter. It is thus seen that the mere statement of H.P. is not sufficient to decide the question, whether the motor will be suitable for service on a line on which this H.P. is demanded of it. We have here an element of uncertainty in the rating which may cause great trouble to buyer and seller. Another source of difficulties and differences is the question of efficiency, especially in direct-coupled generators. The engine-builder guarantees a certain efficiency for the steam-engine and the dynamo-builder does the same for his dynamo. When the two are coupled, it is easy enough to determine the combined efficiency, but it is by no means easy to find out whether each guarantee has been separately fulfilled. Should the combined efficiency fall short of the product of the two guaranteed efficiencies, then the separate determination must be made, and each expert will use a different method giving different results. Now to protect buyer and seller alike it is necessary that the method of testing should be agreed upon beforehand. If the dynamo-builder knows how his machine will be tested, he can in framing his guarantee allow for inaccuracies of the method; the buyer gets his tenders all worked out on the same basis, and can compare them, and the expert who may be called in to test the machinery has no need to invent new methods, but will be simply requested to carry out the tests as agreed beforehand. Such rules for testing efficiency should be simple and capable of being carried out without entailing great expense or disturbance to the regular working of the plant, and they should give the efficiency with a fair degree of accuracy. Absolute accuracy can of course not be expected and is not required; the important point is, that by such rules there should be established beforehand a clear understanding between buyer and seller, and that there should be no possibility of either being unfairly treated. It would be easy to multiply examples to show that a general and if possible international understanding as to the proper way of rating and testing electrical machinery is very desirable. As, however, on this point there will probably be no difference of opinion, the author does not propose to take up the time of the Congress by giving further examples, but he prefers to give an account of what has recently been done in Germany in the direction of establishing standards for the rating and testing of electrical machinery.

The German Association of Electrical Engineers, of which the author has the honour of being Secretary, appointed last year a committee to investigate the question of rating and testing electrical machinery. The report of this committee was presented to the annual meeting of the Association this year, and accepted by it provisionally. As is usual with rules and regulations issued by the Association, their definite adoption is only decided upon after they have been provisionally in use for a year or two, the object being to provide an opportunity for testing the rules in practical work and for amending or altering them, if the necessity arises, before final adoption, which takes place at some future annual meeting of the Association. Thus the "Standards for Rating and Testing Electrical Machinery" are still subject to revision. The committee has been reappointed with instructions to collect information as to how the standards work in practice, and to bring up a second report next year. In the Appendix (page 830) is given a translation of these standards. They do not relate to all electrical apparatus, but only to that kind which is generally understood by the term machines and transformers. Thus, generators, motors, rotary converters, motor generators, and static transformers are provided for by these standards, but not switches, switch gear, measuring instruments, fuses, automatic circuit breakers, and other apparatus. It is not intended that these standards should interfere with any special conditions, which buyer and seller may agree upon; but if there are no special conditions previously arranged between the parties, then they shall both be bound by the standards of the Association.

As regards the rating of apparatus a distinction is made, according to the time during which it is used. Three classes are provided, namely for

(*a*) Intermittent use.
(*b*) Short-time use.
(*c*) Continuous use.

The same piece of apparatus may be used under all three conditions, but then its rating would be different. Thus a motor which under (*c*) would be rated at 12 H.P., may be rated under (*b*) as 20 H.P. and under (*a*) as 25 H.P. The power is to be stated on the name-plate, and the test is to be made according to the power stated. Thus if the motor is rated at 25 H.P. for intermittent use, it shall be tested at 25 H.P. for one hour. If the name-plate bears the inscription 20 H.P. for two hours (condition *b*) then the motor shall be tested for two hours under a load of 20 H.P. If the name-plate bears the inscription 12 H.P. continuous, then the motor shall be tested with that load during 10 hours or a shorter time, if that suffices to bring it to the final temperature. In all three cases the temperature rise must remain within the limits prescribed. These are for cotton-covered wire 50° C., for paper-covered wires 60° C., and for wires insulated with mica, asbestos, etc., 80° C. For tramway motors somewhat higher limits are allowed, namely, 70°, 80° and 100° C. respectively.

The conditions as to overload are not very rigorous. As far as generators are concerned, the capacity to give an increased output is generally limited by the prime mover, and to demand an excess of output beyond that which the prime mover can deal with would uselessly increase the cost of the electrical part of the plant. In motors, transformers, and converters, somewhat larger overloads are possible, but then only momentarily, and for this reason the standards only require the overload test to be made during three minutes. The measurement of insulation resistance is not prescribed, but a breakdown test at high voltage. Also this test has been advisedly kept within reasonable limits, since a breakdown test at extremely high voltage may, even if the machine stands it, injure it just as the cold-water test of a boiler, if made under excessive pressure, may permanently weaken the plates.

The most difficult task of the committee was the framing of rules for testing efficiency. In all eight methods are given, and the maker of the apparatus has the right to specify which method shall be used in testing the efficiency. In framing the methods the committee was guided by considerations of expediency. It would perhaps have been possible to devise methods which from a theoretical point of view promised a greater degree of accuracy, but there was the danger that such very perfect methods would entail so large an expenditure of time and money, and would cause so much disturbance to the regular working of the plant that they would not be used. Efficiency tests are ordinarily carried out only after the plant has been at work some time. Any test which causes considerable disturbance to the regular use of the plant is therefore inadmissible; and although it would in the interest of science be very desirable to make efficiency tests with the highest possible degree of accuracy, practical considerations must lead us to be satisfied with approximate methods which can be easily carried out. The danger that either the maker of the apparatus, or the buyer of it, may suffer through the inaccuracy of the efficiency test is provided against by the stipulation that the method under which the efficiency shall be tested must be stated in the tender. Both parties know therefore beforehand, what sources of error may arise, and the maker of the apparatus can frame his guarantee accordingly.

APPENDIX.

Standards for Rating and Testing Electrical Machinery, provisionally adopted by the German Association of Electrical Engineers at the meeting in Dresden, on 28*th June* 1901.

Definitions.

Dynamo or *Generator* is a rotatory machine for the conversion of mechanical into electrical power.

Motor is a rotatory machine for converting electrical into mechanical power.

Motor-Generator is a duplex machine consisting of motor and generator directly coupled.

Converter is a machine in which the conversion of current takes place in one armature.

The word *machine* used hereunder shall mean either of the above articles according to the context.

Armature in a machine is the part in which by the action of a magnetic flux electromotive forces are developed.

Transformer is an alternating current apparatus without moving parts for the conversion of electric current into electric power.

Pressure in three-phase current is the pressure between any two of the three main conductors.

Ratio in transformers is the voltage ratio at no load.

Frequency is the number of complete periods per second.

Rules given for single phase current apply also, as far as is compatible with the context, to polyphase current.

General.

§ 1. The following rules shall only apply as far as they are not changed or superseded by conditions of delivery specially agreed upon. The §§ 4, 5, 6 concerning the name-plates are, however, always to be observed. Machines or transformers without name-plates, or with name-plates not in accordance with those required, will be deemed not to comply with these standards.

Power.

§ 2. The power of all machines and transformers is to be defined according to the output. It must be stated for continuous current in kilowatts (Kw.), and for alternating current in kilowatts, with the addition of the power factor. Motors are to be rated according to the output of mechanical power expressed in horse-power (H.P.).

In addition to the output there must be stated on the name-plate, or a special plate, the normal values of speed frequency, pressure, and current.

§ 3. As regards the output the following working conditions are to be distinguished:—

(*a*) Intermittent use, in which periods of work and rest each lasting only a few minutes alternate (motors for cranes, hoists, tramcars, etc.).

(*b*) Short-time use, in which the period of work is shorter than necessary to reach the final temperature, and the period of rest is long enough to permit the temperature to drop approximately to that of the air.

(*c*) Continuous use, in which the period of work is long enough for the final temperature to be reached.

§ 4. The power of machines and transformers for intermittent use is to be rated as that power which can be given off during one hour without the temperature rising above the limits stated below. This power is to be stated on a plate with the designation "*intermittent.*"

§ 5. The power of machines and transformers for short-time use is to be rated as that power which can be given off during the working time agreed upon, without the temperature rising above the limits stated below. This power is to be stated on a plate with the designation "*for . . . . hours.*"

§ 6. The power of machines and transformers for continuous use is to be rated as that power which can be given off during any length of time, without the temperature rising above the limits stated below. This power is to be stated on a plate with the designation "*continuous.*"

§ 7. It is permitted to state the power for different working conditions on the same plate.

§ 8. For generators and converters for variable pressure, the plate need only contain the normal values of pressure, current, and speed; the limiting values belonging together must, however, be stated in the conditions of delivery.

§ 9. Machines with commutator must, if the brushes are shifted into the best positions, run at any load within the prescribed limits so far sparklessly that no treatment of the commutator with glass paper, etc., is necessary until after at least twenty-four hours' working.

Rise of Temperature.

§ 10. The temperature rise shall be measured at normal load as defined by the above working conditions, namely:—

1. For intermittent use after working one hour.
2. For short-time use after working uninterruptedly during the time stated on the plate.
3. For continuous use.
   (*a*) For machines after working ten hours.
   (*b*) For transformers after working long enough to reach the final temperature.

§ 11. If with small machines there is no doubt that the final temperature is reached under ten hours, then the temperature rise may be measured after a correspondingly shorter working time.

§ 12. For testing the temperature rise, the various casings or coverings provided for normal working must not be taken away, opened, or considerably altered. If for normal work special provision is made for cooling, this may be provided for also during the test, but it is not permitted when testing tramway motors to artificially produce a current of air as an equivalent for the motion of the car.

§ 13. As external temperature is to be taken that of the incoming current of air, or, if no current is observable, the mean temperature of the surrounding air about 1 mètre distant on all sides and at the level of the centre of the machine. The temperature of the air is to be measured in regular intervals during the last quarter of the time of test and the average of all these readings is to be taken.

§ 14. If a thermometer is used, care must be taken to provide for an efficient transmission of heat between the part to be tested and the bulk of the thermometer by using a bedding of tinfoil. To prevent radiation, the bulb and the part to be measured are to be protected by a covering of a bad conductor such as dry wadding or waste. The reading must be taken after the mercury has ceased to rise.

§ 15. With the exception of continuous current field coils, all parts of generators and motors are to be tested for temperature rise by means of a thermometer. As far as possible the points of maximum temperature are to be ascertained, and the readings for those points are to be considered in determining the temperature rise.

§ 16. The temperature of continuous current field coils is to be determined from the increase of resistance. Unless the temperature-coefficient is specially determined it is to be taken as 0·004 per degree Centigrade.

§ 17. For transformers the highest temperature indicated by the thermometer at any point of the windings is to be taken. If oil be used, the temperature is measured in the upper strata of the oil.

§ 18. For ordinary cases and if the air-temperature does not exceed 35° C. (95° F.), the temperature-rise of insulated conductors, commutators, and slip-rings shall not exceed the following values:—

With cotton insulation	50° C. (90° F.)
With paper insulation	60° C. (108° F.)
With insulation consisting of mica, asbestos, or preparations containing these materials .	80° C. (144° F.)
For windings which are not in motion these values may be exceeded by 10° C. (18° F.)	

§ 19. In tramway motors when tested in the testing-room in the workshop after one hour continuous work, the rise of temperature should not exceed the following values:—

With cotton insulation	70° C. (126° F.)
With paper insulation	80° C. (144° F.)
With insulation consisting of mica, asbestos, or preparations containing these materials	100° C. (180° F.)

§ 20. For combined insulation the lower limit must be taken.

§ 21. In windings which are permanently short-circuited, the above limits may be exceeded.

Overload.

§ 22. In practical working, overload should only occur for a short time or under such temperature conditions that the permissible temperature-rise is not exceeded. With this limitation, machines and transformers must be capable of overload within the following limits:—

Generators Motors Converters	25 per cent. for half-an-hour, on condition that in the case of alternators the power factor is not lower than marked on the plate.
Motors Converters Transformers	40 per cent. during three minutes, on condition that for motors the normal pressure at the terminals is kept up.

The commutator of continuous-current machines and converters must not be injured by the test for overload to such an extent that it fails to comply with § 9.

§ 23. If tested at constant speed, the pressure of generators must be capable of being kept constant up to 15 per cent. overload, provided that when testing alternators the power factor is not kept lower than stated on the plate.

§ 24. The test is intended to prove the mechanical and electrical capacity to take an overload without regard to heating. For this reason the test is to be begun under such temperature conditions that the permissible temperature rise is thereby not exceeded.

§ 25. These regulations also apply to generators for variable pressure in which the variation of pressure is attained by approximately proportional change in the speed. In generators with approximately constant speed (which work at normal pressure with a weakened field), the overload test is not to be made. The same applies to motors if they work with a weakened field.

Insulation.

§ 26. A measurement of insulation resistance is not prescribed, but a test of dielectric strength which has to be made at the makers, and with larger apparatus also on the site before starting the plant. Machines and transformers must be capable of withstanding the test for half-an-hour with a pressure exceeding the normal pressure by the amount stated below. The test is to be made when the apparatus is warm, and shall be repeated only in exceptiona cases, the object of this restriction being to avoid damage.

Machines and transformers up to 5,000 volts shall be tested for dielectric strength with double their working pressure, but not with a smaller pressure than 100 volts. If the working pressure lies between 5,000 and 10,000 volts the test pressure must exceed it by 5,000 volts. If the working pressure is above 10,000 volts the test pressure should exceed it by 50 per cent.

§ 27. The test pressure is to be applied between winding and frame, and for bodily contiguous but electrically separated windings between those windings. In the latter case the test pressure is to be determined with reference to the winding of higher pressure.

§ 28. Two electrically connected windings of different pressure are to be tested to frame with the test-pressure corresponding with the winding of higher pressure.

§ 29. If machines or transformers are connected in series, then in addition to the above tests the connected windings are to be tested to frame with a test pressure determined with reference to the pressure in the whole system.

§ 30. The above regulations apply to cases where the testing current is of the same kind as the working current. If continuous current apparatus is to be tested with an alternating electromotive force, then the effective test-pressure need only be 70 per cent. of the value as above defined. If, on the other hand, alternating-current apparatus is to be tested with a continuous electromotive force, then the test pressure must be by 40 per cent. greater than above defined.

§ 31. If a winding is normally connected to frame, the connection must be severed during the test. In this case the test pressure is determined with reference to the highest pressure which obtains normally between any point of the winding and the frame.

§ 32. Magnet coils excited from an independent source of electromotive force shall be tested with three times the normal working pressure, but not less than 100 volts.

§. 33. The winding on the secondary armature of an induction motor is to be tested with twice the working pressure occurring at starting, but not less than 100 volts. Squirrel-cage armatures need not be tested.

Efficiency.

§ 34. The efficiency is the ratio of power given out to power put in. It may be determined by direct measurement of output and input, or indirectly by measurement of losses. The indirect methods are more easily carried out, less influenced by errors of observation, and for these reasons to be preferred as a rule. In stating the efficiency the method according to which it shall be or has been tested must be also stated, for which purpose a reference to the corresponding paragraph of these standards is sufficient. The efficiency must be stated for the temperature condition corresponding with normal working.

The efficiency is to be stated with regard to the working condition (compare §§ 4, 5, 6). If the efficiency is stated without reference to load, then it shall be deemed to refer to normal load.

The power required for excitation or loss in the field rheostat is to be calculated as a loss when determining the efficiency.

§ 35. For generators, synchronous motors, and transformers, the efficiency is to be stated on the supposition of equality of phase between current and pressure.

§ 36. When machines have separate exciters, the efficiency of both machines must be given separately.

Methods for the Determination of Efficiency.

§ 37. *Direct Electrical Method.*—This method can be employed with motor generators, converters, and transformers by measuring electrically the power put in and given out. In order to employ similar measuring instruments, it is desirable in this method to test similar machines or transformers in pairs.

§ 38. *Indirect Electrical Method.*—If two similar machines are obtainable they are mechanically and electrically coupled so that one runs as generator and the other as motor. The system is driven by means of current from an external source in such a way that only the power required to cover the losses is supplied and measured. The arrangement is to be regulated so that the mean between the power given to the motor and given out by the generator is as nearly as possible the normal output of the single machine, this average value being determined by measurement. The power supplied to cover the losses can also be applied mechanically and measured electrically.

If belt gearing cannot be avoided in this measurement, the losses occasioned by it are to be taken account of.

The method above described can also be employed with transformers if the latter are identical so far as output, pressure, and frequency are concerned. The loss occurring in any auxiliary apparatus is to be taken account of.

§ 39. *The Direct Brake Method.*—This method is generally employed for small motors, but can also be employed for a small generator which is being driven as a motor, in which case the conditions must be so chosen that the magnetic and mechanical stresses, speed, and output differ as little as possible from what they would be if the machine were used as a generator.

§ 40. *Indirect Brake Method.*—If a generator or motor of corresponding output is obtainable whose efficiency at various loads is accurately known, this can be employed as a brake or as a driving motor. If a belt drive is employed the loss in it must be taken account of.

§ 41. *No Load Method.*—The machine is run light as a motor and the loss at normal speed and field strength is determined. This represents the losses due to air, bearing and brush friction, hysteresis and eddy currents whose variation with the load is not taken account of. By electrical measurements and calculations the C^2R loss in the field, armature, brushes and contact resistances at the corresponding load is determined when the machine is warm. In the case of asynchronous motors the losses in the secondary armature may be determined by measurements of slip, instead of by measurements of resistance. The losses in regulating resistances in series with the field windings are to be taken account of. This method may also be applied for transformers.

The sum of the losses determined as above is called the "*measured loss.*" The efficiency is to be considered as the ratio of output to the sum of output and measured loss.

§ 42. *Auxiliary Motor Method.*—If there are difficulties in the way of direct determination of the friction losses as well as of the hysteresis and eddy currents, or if a suitable source of current cannot be obtained for driving the machine, the frictional, hysteresis and eddy current losses may be determined by means of an auxiliary motor. The machine to be tested is given its normal excitation, and the power required to drive the auxiliary motor is determined. The losses in the auxiliary motor (and if a belt drive be employed the losses in this) are then deducted, having been obtained by measurements and calculations as in § 41. A steam-engine can be employed in place of the auxiliary motor, if it can be disconnected from the dynamo. In this case the steam-engine is indicated when driving the generator at light load at normal speed and excitation, and then the steam-engine is indicated again after the dynamo has been uncoupled. The difference between the two indicated horse-powers may be taken as the light-load losses of the generator. This method must be used with great care on account of the inaccuracy of light-load diagrams.

§ 43. *Indicator Method.*—If the generator is driven directly by a steam-engine and cannot be uncoupled, the efficiency may be determined without regard to friction. The hysteresis and eddy current losses occurring at no-load at the normal speed and pressure are determined by taking indicator diagrams with the machine excited and not excited. If the excitation is provided from the same steam-engine, the power required for it is to be subtracted. The difference is regarded as loss due to hysteresis and eddy currents, and no account is taken of its variation with load. By means of electrical measurements and calculations the ohmic loss in field, armature, and brushes is then determined. Account is to be taken of the fact that the contact resistance of the brushes varies with the speed and current density, and that the ohmic losses of the windings must be calculated for the working temperature. Losses occurring in normal working in field rheostats are to be included in the calculation. The sum of the losses as above determined is called the "*measured loss.*" The efficiency is to be considered as the ratio of output to the sum of output and measured loss. This method must be used with great care on account of the inaccuracy of light-load diagrams.

§ 44. *Separation Method.*—For machines which have no bearings of their own the efficiency shall be determined without regard to friction in the following manner. The loss due to eddy currents and hysteresis is to be determined in similar manner as prescribed for the "no-load method" by running the machine light as a motor. In order to separate the loss due to air, brush, and journal friction from the loss due to eddy currents and hysteresis proceed as follows. The machine is to be run without load at different pressure but normal speed. It is advisable to reduce the pressure as far as possible after having taken readings at normal pressure, and if possible at 25 per cent. excess pressure. The readings are to be plotted graphically, and the curve prolonged backwards to the point of zero pressure. The corresponding value is the loss due to friction, and is to be deducted from the loss determined at normal pressure. The rest is to be considered as loss due to eddy currents and hysteresis, and no account is taken of its variation with load. The other losses are to be determined as in § 41. The sum of the losses due to eddy currents, hysteresis, resistance of field, armature and brush contacts is called the *measured loss.* The efficiency is to be considered as the ratio of output to the sum of output and measured loss. The determination of the losses due to eddy currents and hysteresis can also be made by means of an auxiliary motor.

Change of Pressure.

§ 45. The change of pressure in alternators is to be stated for normal armature current when the load is non-inductive, and for one-third of normal armature current when the load is inductive with a power factor not exceeding 0·3.

§ 46. The change of pressure at non-inductive load is that variation of pressure which is observed on removing the full working load (power factor = 1), whilst not altering the speed and full load excitation.

§ 47. The change of pressure at inductive load is the variation of pressure which is observed if the armature current is switched off whilst speed and excitation remain unaltered. Before switching off, the machine must be loaded to a third of normal armature current, the power factor not exceeding 0·3, and the excitation must be such as to produce at that load normal terminal pressure.

§ 48. Machines for inductionless load need not be tested as described in § 47, and machines for inductive load need not be tested as described in § 46.

§ 49. If continuous-current machines are to be tested for variations in pressure, the following is to be observed :—Continuous-current machines with shunt, compound, or separate excitation, are tested at four different approximately equi-distant loads from full load at normal pressure to no-load, without the excitation being adjusted. The difference between the greatest and smallest observed pressure is to be taken as the pressure variation. As regards the position of brushes during this test the same practice as agreed on for ordinary working shall be adhered to.

§ 50. For transformers the ohmic loss of pressure and the short-circuit pressure with the normal secondary current has to be given, both for the secondary circuit. The ohmic loss is taken to be the pressure variation for inductionless load; the short-circuit pressure as the pressure variation for inductive load. It is permissible to make the test with a current differing slightly from the normal, in which cases the variations in pressure must be calculated proportionately for normal current.

Discussion.

The Chairman said that Mr. Kapp had dealt with a subject which was of great and growing importance, both commercially and from a scientific point of view, and he hoped they might be able to reward his Paper by a good discussion. Before doing that, he would ask them to pass a vote of thanks to him for the Paper he had just read.

Mr. R. W. Weekes agreed that regulations like those given by the author would remove the cause of many disputes between consulting engineers and contractors. He thought, however, that the overload limit of 25 per cent. was too low. The construction of dynamo, motor, and transformers should be such that they could stand much larger increases in load without permanent injury resulting.

Mr. Druitt Halpin said that the author referred to the use of motors in driving centrifugals. That was a special case, and he supposed Mr. Kapp probably referred to the use of centrifugals in Germany for the production of beetroot sugar. He had had to go into that question some time ago, and found that for German beetroot sugar they were very well adapted, but for cane sugar they were not so well adapted; for this reason the work of a centrifugal was divided into two parts, the time necessary to get up speed, and the time to run; and in beet sugar the time of running, after having got up speed, was, of course, out of all proportion to the time required to get up the speed. With cane sugar the reverse was the case. In beet sugar it was totally different, the machines running for a long time on a light steady load. The author also referred to many machines for private lighting that had only to run three hours, and in that time they had not time to burn out. He remembered making once, with the late Mr. P. W. Willans, two tests on separate occasions of a machine which was built by a very well-known firm, and the time was not anything like three hours. It was more like

(Mr. Druitt Halpin.)

half an hour. He said to Mr. Willans "Shall we go on or burn it out?" The third test resulted similarly, and it would have burned out if he had gone very much longer, considerably under three hours.

Colonel P. E. HUBER, of Zürich, felt much indebted to Mr. Kapp for his Paper showing the absolute necessity to come to general rules for the testing of electrical machines and apparatus. The speaker's experience indicated that a test of eight to ten hours was not always conclusive for machines having to stand continuous work under full load as used for electro-chemical purposes, where machines had no rest day and night for months. Such machines sometimes showed their defects with regard to over-heating only after two or three days' continuous working.

Mr. E. C. DE SEGUNDO was not prepared to speak on the main issues of the Paper, but might be allowed to say that Mr. Kapp's arguments were very sound, and might be taken as advice to the public in general and to manufacturers in particular to employ a consulting engineer, and to see that he was a good one. The cause of the disputes that so frequently arose between client and manufacturer was to be found, in nine cases out of ten, in the indefiniteness of the specification. It required a special education and a great deal of experience to draw a specification properly. If any plant was ordered on behalf of a client, it should be stated exactly what that plant was to be, exactly what it had to do, and the conditions under which it was to be done. Then there could be no dispute whatever as to the conditions under which it was to be tested. If a certain dynamo was specified to give so many ampères at so many volts, and afterwards it was found that the dynamo behaved in a way that was not contemplated by the buyer, then the question arose as to whose fault it was, exactly as Mr. Kapp pointed out in the case of steam dynamos; and the advent of experts on the scene not infrequently made confusion worse confounded. He thought Mr. Kapp's Paper ought to be taken not only as a valuable and important contribution, but also as an indication that the education of engineers in the direction of drawing specifications ought not to be neglected.

Mr. MICHAEL LONGRIDGE thought it would be well if the maximum permissible temperatures for various insulating materials and time-limits could be approximately settled and stated in the proposed rules, since a rise in temperature which might be perfectly harmless to a machine working in a cool place might be dangerous if the temperature of the surrounding air were high.

Mr. KAPP, in reply, said that the last speaker had pointed out a very important matter, but one which had not been overlooked, though it had not been mentioned in his summary. Paragraph 18 (page 833) stated that "for ordinary cases, and if the air temperature does not exceed 35° C. (95° F.), the temperature-rise of insulated conductors, commutators, and slip-rings shall not exceed the following values," etc. They had thus taken the final temperature into account. Those figures were the result of experiments; they had found that the cotton used for covering wire would, at an absolute temperature a little short of 100° C., become deteriorated, but paper would stand a good deal more, and they had fixed the temperature-rises with due regard to the result of these experiments.

Mr. Weekes was not satisfied with the amount of overload which was imposed. Perhaps he was right, but they must not demand too much of makers. It would certainly lower the efficiency of the machine, and increase its price if the maker were asked to guarantee a very much greater overload. The momentary overload of a machine might be high, and that was provided for in the rules, but a continuous overload needed not be higher than the overload which the engine could carry.

He was not sufficiently acquainted with the manufacture of sugar to go into the point raised by Mr. Halpin. All the centrifugals which he had seen in Germany took most of the power in getting up speed, then ran for a few minutes, and were shut down again. The motor of the centrifugal, generally a three-phase motor, was very heavily overloaded, but only for some minutes. After that it got a rest of fifteen or twenty minutes.

Colonel Huber had brought a point before them which was very important, namely, the question of how long the full-load test of a

(Mr. Kapp.)

dynamo should be extended. He was quite right. Ten hours for big machines might or might not be enough; that depended on the construction of the machines. The author had recently tested a machine of 1,000 kilowatts, which was perfectly ventilated. It had in the armature five air-ducts through the iron, and plenty of air went through. That machine attained its final temperature in about ten hours. Other machines were not so well ventilated, and it certainly would be necessary to work them for a longer time to get the final temperature. They thought if they specified a twenty-four hours' test, it would hardly be carried out. Those present who had made such tests knew what it was to be even only ten hours on duty in an engine-room, and taking readings all the time. One got very tired and sleepy towards evening, and one was not very eager to work longer than absolutely necessary. Modern machines were so well ventilated that they remained, even in long tests, generally very much below the prescribed heat limit. He had often found in armatures a rise of only 30°, and in the field coils even less. If a limit of 50° was given, and it was seen that it was not half reached after ten hours whilst the curve was bending over, he thought the test might be knocked off and satisfactorily attained. It was a point which might be re-considered, and he was glad Colonel Huber had drawn attention to it.

Mr. Segundo's remark did not concern so much the subject of the Paper as the men who had to do the work. He quite agreed with him that buyers ought to employ good consulting engineers when it was a question of large machines, but there were many cases where a consulting engineer need not be employed. One ought to be able to buy a 20-kilowatt dynamo just as one bought a pulsometer, a feed-pump, or a thrashing machine. In buying such well-known articles a consulting engineer would not be employed. It would be known what was to be supplied. Why should it not be so in the case of electric machines? If one wanted to buy a 20-H.P. motor, one ought to know what to ask for and be able to get it. Unfortunately, there was a most pernicious cutting of prices in the electrical industries, and one did not always get what one expected, and what the makers professed to sell. For such cases these rules had been framed.

They were by no means intended to do away with consulting engineers, as would be seen from the introductory clause, which provided that these rules should not apply if the buyer and seller had agreed upon special conditions.

The Chairman said the time was then so near one o'clock that they would not be able to take the remaining Papers that day. Mr. Lenke's Paper would thus have to stand over, and would be taken first on the following morning. Mr. Rateau's Paper would be taken with his second Paper on Thursday.

SOME EXPERIENCES AND RESULTS DERIVED FROM THE USE OF HIGHLY SUPERHEATED STEAM IN ENGINES.

By Mr. R. LENKE, of Erith.

In no branch of heat-engine building has such an amount of study been spent as in steam-engines, from Watt's time up to to-day. The economy of the steam-engine is, in spite of all efforts, not the best, and the steam-engine in its highest perfection attainable at present cannot claim the first place in comparison with other heat-engines. And so the problem of generating and using superheated steam has become a question, from the solution of which a considerable stride in improving economy has been expected and really made.

Superheated steam is generated by the addition of heat to saturated steam. The behaviour of superheated steam is similar to that of gases; it is a very bad conductor of heat, and has the special peculiarity of being able to lose a certain amount of heat without becoming saturated or wet steam. The thermal capacity of steam is only 0·48, therefore very little heat is required to superheat steam; but as the steam loses the heat as quickly as it acquires it, every passage conveying superheated steam must be well covered with non-conducting material. Although there are some losses when using superheated steam on account of the heat radiation, they are very much smaller, because the loss of heat from superheated steam has lower calorific value than the latent heat of saturated steam.

Superheated steam has a greater volume per unit of weight than saturated steam at the same pressure, hence one advantage, and the higher the temperature, the greater this advantage. At various pressures and temperatures the increase of volume may be taken from the following Table 1:—

TABLE 1.

Pressure.	390° F.	570° F.	750° F.
70	1·1	1·33	1·57
115	1·06	1·29	1·52
170	1·02	1·24	1·46

Table 1 shows that the higher the pressure is, the smaller the increase of volume; and it is proved from practice that the advantage with lower pressure is indeed greater in proportion than with higher pressures.

The question may arise whether the increase of volume does not require more additional heat than the benefit derived from it is worth. To show this clearly Table 2 has been prepared expressing how many B.T.U. less are required to produce 1 cubic foot of superheated steam than of saturated steam at the same pressure. For various pressures and temperatures the total heat per cubic foot is as follows:—

TABLE 2.

Pressure.	Saturated.	390° F.	570° F.	750° F.
70	233	219	192	175
115	350	337	297	267
170	492	485	432	398

that is, to produce, for example, 1 cubic foot of steam at 115 lbs. pressure and a temperature of 570° F.,

$$\frac{350 - 297}{350} = 15 \text{ per cent.,}$$

less heat is required than to produce 1 cubic foot of saturated steam at the same pressure. With saturated steam engines, 20 per cent. to 25 per cent. of admitted steam is condensed during the admission period, consequently the practical steam consumption is very much in excess of the theoretical. Superheated steam does not condense during this period if sufficiently superheated, hence another advantage.

The economy effected by using superheated steam in engines is very remarkable, and, acknowledging this fact, a great number of steam users all over the world superheat the steam, although in many cases only a few degrees, yet a considerable saving in steam and coal is always the result. To obtain the full benefit, the required temperature of steam is 660° to 700° F., and to stand this temperature, the engines must be specially designed. It is not sufficient to use mineral oil with a very high flash point, and anyone who tries to supply an existing engine of any kind with steam at that temperature will have a very unpleasant experience, even when using the above-mentioned oil.

The introduction of superheated steam into engines largely influences the expansion of the heated parts. Engines always gave great trouble when the distribution of metal in the cylinders was not uniform, as parts with more metal expanded most, and forced the cylinder walls towards the inside and made the cylinder out of shape. When using liners in the cylinders, they were squeezed in at the ends, decreasing the diameter, and jamming the piston body if sufficient clearance was not provided. With steam-jackets heated with steam of 500° F., the lubrication ceased as the cylinder walls became too much heated, consequently it was found necessary to do away with jackets, or if jackets were already provided, not to pass steam through them. Pistons constructed on the Ramsbottom type always worked satisfactorily, except in the case of pistons fitted with steel springs, when they were in contact with highly superheated steam.

Any kind of gun-metal gets brittle after a very short time, therefore valves, seats, and all parts in direct contact with superheated steam, must be made of cast-iron or other suitable mixture. Copper also loses about 40 per cent. of its strength at that temperature, consequently copper bends in pipes are not practicable. The best material for piping has proved to be wrought iron and steel, each pipe being as long as possible, to have the least number of flanges. For long, straight pipe connections, provision must be made to meet the expansion, which is, at 700° F., 0·0037 of the length, so that, for example, 100 feet of pipe extends 0·37 of a foot, or nearly $4\frac{1}{2}$ inches.

Glands and stuffing-boxes at first frightened users, so the engines were constructed single-acting to avoid the use of glands, but no serious difficulties have arisen on that account. It is advisable to place the stuffing-box as far as possible from the cylinder-end to keep it well away from the hottest parts, and to allow of as much radiation as possible. Sufficient clearance in the neck bush should be made to allow for the expansion of piston-rod, and no metal with a melting temperature below that of the steam should be used.

Valves and valve gears are influenced in the same way by superheated steam. Valves containing many ribs or different thicknesses of metal (in section), such as plain slide-valves or Corliss valves of the usual construction, are not suitable for high temperatures. A Corliss valve of medium size will stand 480° to 500° F., but no more, and the latter temperature very seldom. The smaller the plain slide-valves are, the higher temperature they will stand: large slide-valves will hardly stand even slightly superheated steam, if no provision is made for forced lubrication of the valve face.

Piston-valves have proved to be most suitable for the highest temperature, owing to their uniform distribution of metal, but even with this sort of valve certain experience is necessary to get them in good working order. With ground valves, the ribs holding the boss for the valve spindle must not begin within the working surface of the valve, but have to be placed beyond that, because they expand and make the valve polygonal. The valves must be ground in other liners to those in which they are to work in the engine; the former liners have to be smaller in diameter to secure more clearance to provide for the expansion of the valves. The cylinder expands in length more or less than the steam-chest, causing thereby deformation of the latter, which must be carefully considered in design. It is best to work the valves in liners fixed in the cylinder and with a small clearance, sufficient to allow for the deformation of the steam-chest. With this construction it is of course necessary to make steam-tight joints between the several ports, and this is best done by stepping the liners and seats and using narrow asbestos rings for each step. The liner is then forced on to the small seats by set screws in the cover, these asbestos rings making a lasting joint. Long valves cast in one piece become scored, whether they are cooled from inside with exhaust steam or not; consequently all valves should be made as short as possible. Rings and springs in valves cannot be recommended, as the steam comes behind the rings and increases the pressure, causing friction and therefore increased oil consumption. As it is impossible to rely on tightness of piston valves, they must be made as small in diameter as possible. It may be stated here that superheated steam can travel at 30 to 40 per cent. higher speed through steam ports than saturated steam, and this fact has to be considered during construction.

Two piston-valves working one in the other, as the Rider or Meyer valves, are impracticable for superheated steam. If engines of that type are intended to be worked with superheated steam, each valve must work in a separate chamber.

Double-beat valves can also be recommended as being safe, but they require a special arrangement, which is not always obtainable with every gear. Very often it happens when warming up the engines that the valve spindles get hotter than the gland-boxes, and on starting the engine, the friction between spindle and stuffing-box is greater than the power of the spring, and if the valves are not positively driven, they remain open during the full stroke.

An engine constructed in accordance with the principles just explained is as safe with superheated steam as any other engine with saturated steam. From the experience over several years, it is not necessary to be bound to single-acting engines.

Besides the economy, the use of highly superheated steam has some other advantages which are also important. It makes the steam consumption nearly independent of the size of engine, as a small engine has about the same steam consumption as a large one, as for example: an 80 H.P. compound condensing engine uses 10·45 lbs. of steam at 160 lbs. pressure, and a 1,000 H.P. engine uses 9 lbs. of steam per I.H.P. per hour. The use of highly superheated steam does not require high boiler-pressures, 160 lbs. is the highest to be recommended, as no advantage can be derived by exceeding this. As the amount of heat transmitted from the steam to cylinder walls, and vice versa, is much lower with superheated steam than with saturated steam, the whole range of temperature from boiler pressure to vacuum can take place in one or two cylinders, so that the use of a triple-expansion engine does not make the slightest improvement in economy. It is not intended to be understood that the author proposes to do away with all triple-expansion engines; for very large plants, their use will be necessary for constructive reasons.

With regard to economy obtained from engines working with superheated steam, the gain is derived from the larger volume of the steam and the doing away with initial condensation.

Generally the steam consumption of modern engines working under good conditions may be taken as follows:—

Single-cylinder condensing engines with saturated steam and a pressure of 90 to 100 lbs. per square inch use 19 to 25 lbs. of steam per I.H.P. per hour, corresponding with 373 to 490 B.T.U. per minute. The great difference in temperature between admission and exhaust steam causes much waste by initial condensation, and consequently this type of engine especially favours the use of superheated steam. With superheated steam the consumption has been lowered to 13½ to 15 lbs., corresponding with 290 to 335 B.T.U.

Non-condensing single-cylinder engines gave consumptions of 15 to 18 lbs. of steam per I.H.P. per hour, which is about the same consumption as an average compound condensing engine with saturated steam. The non-condensing compound engine decreases the consumption to 14 to 16 lbs. per I.H.P. per hour. The compound condensing engine is the most economical, and the economy obtained can hardly be reached by a quadruple-expansion engine working at a pressure of 300 lbs. The steam consumption of such an engine either compound or tandem, at 140 lbs. pressure only, never exceeds 10 lbs. per I.H.P. per hour and usually remains below, many tests having proved 8·5 and 8·8 lbs. consumption per I.H.P. To utilise better these temperatures and to work with various loads with safety and nearly uniform economy, Mr. Schmidt has introduced the receiver-heater with automatic valve. The idea is to keep a steady mean temperature of cylinder walls not higher than will make the lubrication unreliable for different rates of expansion.

A few words may be said with regard to the cost of a superheated plant. Superheated steam engines use on an average 30 to 40 per cent. less steam than saturated steam engines of the same type. Consequently boilers can be made 30 per cent. smaller, and the difference in price will nearly cover the cost of the superheater. For the same steam consumption the superheated steam engine is cheaper, as it may be worked with a lower boiler pressure, and it is simpler, *i.e.*, instead of a compound engine with saturated steam, a single cylinder engine with superheated steam may be used, giving the same or better results than the former.

With regard to oil consumption, it was found not to be more than that of an ordinary saturated steam engine. For example: a 120 I.H.P. engine used 4 lbs. of oil in 24 hours, and a 300 I.H.P. Corliss compound engine 2·2 lbs. in 10 hours for both cylinders.

In view of the great advantages of steam superheating, and the great number of engines running at present satisfactorily, it is astonishing that a few failures have caused prejudices amongst some engineers, who make the general introduction of the use of superheated steam very difficult. It will be worth mentioning that the results of a great number of trials have always proved a great saving in steam and coal, and even with small plants and simple piston-valve engines, almost the same good economy is obtainable as with large engines with most exact valve-gears. It is therefore recommended that superheated steam should be used in connection with *all* engines; the only question to be settled is the degree of superheat, which largely depends on local circumstances and the construction of the engine, and this matter should be left to the judgment of an experienced engineer.

Discussion.

The Chairman thought the use of superheated steam had a very great future before it, and they were indebted to Mr. Lenke for having brought before them in a very interesting Paper a number of practical points to which it would be necessary to attend, if they were to make the use of superheated steam successful. Before commencing the discussion, he would ask them to accord a hearty vote of thanks to Mr. Lenke for his Paper.

Mr. Bryan Donkin, Vice-Chairman, was rather disappointed to find in this excellent Paper no mention of the name or quality of the oil used for lubrication. That was an important point. One would like to know the best oils to use, and the quantity required. Some oils gave good, others bad results. He presumed that the results of the experiments given were chiefly continental. On page 849 there was rather a startling statement, namely, that with saturated steam 20 to 25 per cent. of the admitted steam was condensed during the admission period. That might be so in single-cylinder non-jacketed engines, but in a thoroughly well jacketed cylinder he doubted whether it would be so much. From many continental tests with the very best triple 1,000 H.P. engines with dry or highly superheated steam, little economy was found due to superheating. He was a strong advocate of superheated steam, and was pleased to see so many good experiments recorded.

Mr. C. C. Leach said the experiments were comparisons of the very best economical engines, but nearly all pit engines were most wasteful and too large for the work they had to do. In nearly all cases they had to slow down and work with varying loads; winding engines ran 20 seconds and stopped 5 or 6 seconds. Would superheat get a greater gain of economy with a bad engine than with one of these high-class engines?

Mr. Henry Lea said he would like to ask one question. Supposing that one had a really well-made compound engine working with saturated steam, the stuffing-boxes and piston rings being constructed in the usual manner, what superheat temperature would it be safe to employ with such an engine, using the special oil which Mr. Lenke has found necessary? To alter the engine to conform with the conditions laid down in this Paper would seem to be impossible. It would mean throwing the engine away, and putting down a new one built on Mr. Lenke's lines.

Mr. J. Hartley Wicksteed, Vice-Chairman, said that about eight months ago he had introduced a superheater at the works of his firm, Messrs. Joshua Buckton and Co., Leeds. Their Lancashire boiler was 8 feet 6 inches diameter and 30 feet long, the furnace flues were 3 feet 6 inches diameter, and steam was raised up to 100 lbs. pressure. The superheater consisted of long U-shaped tubes, which hung down from a cast-iron box with a division, so that the steam passed down the side of the U furthest from the flame and came up the sides of the U closest to the flame. The gases impinged upon these bent pipes right opposite the furnace flues, and before they went round the sides and bottom of the boiler to escape up the chimney. They distributed about half their power to distances of 150 feet from the central boiler, and the other half of the power they took as near the boiler as possible. The engines were of different types, some of them had ordinary slide-valves, some of them had double-beat trip-valves for letting in the steam, and Corliss valves for the exhaust, and some of them were steam-hammers, with piston-valves of some sort. They had not had the slightest difficulty, and there had been less trouble with cylinder-covers and pipe-joints. All the engines had run more cheerfully, their shafting made more revolutions per hour, and maintained its speed better with extra loads. The pressure was 100 lbs., and the temperature therefore with saturated steam would be about 340° F.; he thought the temperature they got from the superheater, which was superheating the whole of the steam that was used out of the boiler, was about 500° F. The consequence was they were getting only 160° of

(Mr. J. Hartley Wicksteed.)

superheat. He supposed that was the reason they had had no trouble, but they were satisfied that they had a great deal of benefit.

Mr. Michael Longridge said that the prevention of cylinder condensation considered in the Paper was not the only and, perhaps for the North of England where coal was cheap, not the most promising application of superheating. Superheated steam could also be used in some cases with great advantage to heat and evaporate water. In this connection the name of McPhail, of Wakefield, should be mentioned, not only because he had shown how the output of a boiler could be largely increased without materially increasing the space occupied or watering the steam, but because he had shown engineers how to make a simple and durable superheater which had served as the prototype of the majority of the superheaters now in use in England. Superheating was also useful as a steam dryer only. In works where there were long steam-pipes leading to scattered engines, a considerable saving could be made by supplying the engines with steam instead of water and steam, and this advantage could be gained by a very moderate degree of superheat.

This entire prevention of cylinder condensation required a higher degree of superheat than could be safely used, except in specially constructed engines, but initial condensation might be materially reduced, and possibly in some cases entirely prevented, by superheating to less than 500° F., a temperature which the Corliss valves in general use seemed to be capable of standing. With a superheat of 100° to 120° F., he thought there would be a saving of 10 to 12 per cent. in the case of a good mill engine.

Professor William Ripper thought the point most engineers wanted to hear about was the extent to which they could safely use superheated steam. He must confess that, if he were a manufacturer already fitted up with good plant, he would feel great hesitation in introducing superheating, after reading the Paper, which drew attention to the many mechanical difficulties involved in the use of high superheat. But it must be noted that the difficulties applied to high superheat only, and the practical point was to what extent was it applicable to ordinary plant such as Mr. Wicksteed had been describing. He thought one reason why he had no difficulty with superheating was that his apparatus was to some extent similar in its action to the McPhail apparatus, that was to say, the McPhail apparatus was an arrangement by which highly superheated steam before passing to the engines was compelled to pass through water, and the superheater became a kind of steam generator.

Mr. **Wicksteed** said his apparatus was not like that.

Professor **Ripper** continuing, said Mr. Wicksteed allowed the steam to pass through a long series of pipes in the cold air, which had the same cooling effect on the steam. If the steam were of a very high temperature, the chances were that it was 50° or 100° less hot when it reached the engines or steam-hammers; and the result was that they were dealing with low superheated steam, and were not getting the mechanical difficulties that were suggested in the Paper, whilst they were getting the advantages that arose from evaporating the water in the steam-pipes and preventing condensation. There had been quite enough practical experience in this country with low superheating to show that, in an ordinary plant with the appliances just as they were, superheat amounting to 100° to 150° could be quite safely and wisely used, and would work with a considerable economy. If the phenomenal results which were there tabulated had to be expected or attained, it would only be possible to attain them by having an engine specially constructed, in order to avoid the mechanical difficulties which arose from high superheating.

Professor **John Goodman** said it would be interesting to know how much Mr. Wicksteed saved on his coal bill by superheating. His own experience showed 10 per cent. saving for 50 per cent. of superheat. He would like to ask Mr. Lenke what mixture of cast-iron he found best for cylinders working with a high degree of superheat.

Mr. E. **Hall-Brown** said Mr. Lenke's experience in the use of highly superheated steam made his Paper as valuable as it was

(Mr. E. Hall-Brown.)

interesting. As a marine engineer he was anxious to know how far they would be justified in adapting their engines for the use of highly superheated steam. His object in rising therefore was to obtain further information.

Mr. Lenke stated (page 847) that "although there are some losses when using superheated steam on account of the heat radiation, they are much smaller because the loss of heat from superheated steam has lower calorific value than the latent heat of saturated steam." He would like this more fully explained. Again, Mr. Lenke stated (page 849) that to obtain the full benefit, the required temperature of steam was 660° to 700° F. Why stop there? He presumed it was because the mechanical difficulties then became insuperable.

Mr. Lenke referred (page 853) to the cost of a superheated plant, and stated that the reduction allowable in the size of the boilers would cover the cost of the superheater. But what about the engine? He presumed this was also more costly than an engine designed for using saturated steam. It would be interesting to have some figures respecting this point.

In regard to internal lubrication, as many marine engines were run without the use of any cylinder oil, it would seem that more oil must always be used with engines using highly superheated steam.

Professor W. H. Watkinson said that Mr. Lenke's communication was one of great value, and he wished to congratulate him on having compressed so much useful information into so short a Paper. The author, in stating some of the reasons for the great reduction in steam consumption due to superheating, had omitted what was, he believed, one of the principal reasons, namely, the enormous reduction in the leakage past valves and pistons which was effected by the use of superheated steam.

As to the use of special lubricating oil, he had, on one occasion, some difficulty with a Corliss engine of 1,250 I.H.P., and oil at 5*s.* per gallon was tried instead of the oil at 2*s.* 6*d.* per gallon which had been used prior to the adoption of superheating. At the same time slight alterations were made in the engine. When the first barrel of the higher priced oil was finished, the cheaper oil was again tried, and it had been used ever since without the slightest trouble.

Mr. Lenke, in reply, said he must thank them for the kind remarks that had been made about his Paper. He would do his best to reply to these various questions as far as time permitted. In regard to the quality of oil used for engines of the type referred to, he found one made by the Petroleum Raffinerie, Korff, Bremen, to be very suitable, and lately had procured a sample of a new oil made by Snowden, Sons and Co., Millwall, which gave very good results. Exhaustive trials with this oil had not yet been made, so that he was unable to give any definite figures. The price was about 2*s.* 6*d.* a gallon. The tests referred to were made on continental engines, as there were at present only a few small engines running in Great Britain; but in a few months he would be able to publish similar results from engines made and at work in this country. With regard to his figures of 20 to 25 per cent. loss through initial condensation, he had taken this as an average from a great number of trials, though there were engines losing nearly 40 per cent. of steam by condensation. The question as to whether any benefit might be derived from superheating with highly economical saturated steam-engines was best answered by reference to some trials carried out by Professor Schröter on a triple-expansion engine. The engine used 12 lbs. of saturated steam per I.H.P. per hour, a very low steam consumption indeed, but with steam superheated to 500° F. only the steam and coal consumption was reduced 18 per cent. To what degree steam had to be superheated to suit an existing engine should be left to an experienced engineer. No general rule could be given, but in any case a saving in coal was effected by drying the steam, and the farther the engines were from the boiler the greater the saving. For hauling and winding engines superheated steam had also effected a great saving, and for this type of engine the temperature should be a few degrees below the highest temperature so as to allow a

(Mr. Lenke.)

certain rise whilst the engine was standing. 660° to 700° F. had proved to be the highest temperatures which were both well under control and safe for superheater and engine. Beyond that, superheater coils began to anneal and became permeable.

As this Paper was dealing with steam in engines, no names of superheater makers could be mentioned. The metal used for cylinders should be hard, close-grained cast-iron. A question had been raised as to the cost of superheated steam-engines. One essential condition in their construction was simplicity, as would be seen by reference to that part of the Paper dealing with the details of construction. From this it followed that the cost would not be more, but usually less, than for economical saturated steam-engines. Concerning the amount of leakage for valves for saturated and superheated steam, he was inclined to believe that under the same condition the leakage of superheated steam was less than that of saturated steam, but at the present time it was not yet satisfactorily solved. As a matter of fact the same piston-valve leaked less with superheated steam, but this was due to the greater expansion of the valve, as those valves which were tight with superheated steam leaked with saturated steam. With valves equally tight under both conditions the leakage was, as he had said, not yet determined.

Communications.

Mr. D. R. Todd wrote that during the discussion which followed Mr. Lenke's Paper the question of the limit of temperature of superheated steam was raised, and as the writer had had a somewhat unusual experience in this connection, the following notes might be of interest. About two years ago he had to do with several large boiler plants in the neighbourhood of Glasgow, which supplied steam to a number of high-speed engines made by some of the best-known English makers. The boilers were fitted with superheaters. These superheaters were of a type which has been adopted by several manufacturers, namely, a series of small tubes bent in the form of a U, and fixed at their ends to collecting boxes, into one of which the steam from the boilers was passed, and the exit steam taken off the other. The tubes themselves were exposed to the furnace gases, and the trouble experienced in the case in question, where the boiler was of water-tube type, was repeated in other cases with Lancashire and other boilers. Owing to several causes, which it was unnecessary to refer to, the temperature of the superheated steam reached, and sometimes even exceeded, 1,000° F. To produce this condition the tubes and boxes were exposed to such a high temperature that they had apparently become red-hot, and an alarming state of affairs ensued. Trouble was first of all experienced with the engines, in which the metallic packings of the piston-rod and valve-spindles gave out, and the cylinders showed such signs of over-heating that the engine-makers intimated that unless steps were taken to regulate the amount of superheat so that it should not exceed 50° to 60°, they would decline all further responsibility. The superheaters themselves also gave evidence of being in a dangerous condition; while they were at work one could hear steam escaping into the flues, and by opening an inspection-door, which had been arranged for the purpose, it was apparent that the tubes had been distorted, and were showing signs of great distress. The writer thereupon instructed the workmen who had charge of the erection to have the boilers laid off at the following week-end, and on the Sunday morning he made a personal examination of the superheaters. The tubes were found to be badly distorted, and in nearly every instance the expanding had given way; the tubes were quite loose in their seats, the blade of a penknife could be just passed between the tubes and the connecting-box, and they were apparently only prevented from being blown out of their seats by the excessive amount of belling or beading-over which the tube ends had received after the expanding was completed. The boxes were also slightly distorted, but the most remarkable feature was, that in the tubes, which before being fixed in position had been carefully cleaned out, there were a large number of pellets like small marbles, composed apparently of oxide of iron. It was evident from this that, at the 1,000° F. temperature which the thermometer showed, the steam, or at least a portion of it, had reached the point of dissociation, and the oxygen had attacked the tubes, probably the heated condition of the latter favouring the process of chemical combination. No other explanation could account for the presence of those pellets. If, then, as this phenomenon seemed to indicate, the point of dissociation of steam commenced somewhere about 1,000° F., this would fix the limit to which superheating could be carried, unless the superheaters themselves and the walls of the cylinders, valves, &c., with which the steam came in contact, were made of material not subject to oxidization.

Messrs. HICK, HARGREAVES and Co., of Bolton, wrote that their experience did not bear out the statement in Mr. Lenke's Paper as to Corliss valves giving trouble above 450° or, at most, 500° F. They had for more than six years past been supplying superheaters in large and increasing numbers—some hundreds in all—a large proportion being for use in connection with their standard Corliss engines, which were mostly of considerable size; the largest at present working with superheated steam were a set of horizontal cross compounds, giving 2,300 I.H.P., the cylinders being 31 inches and 64 inches, with Corliss valves, stroke 6 feet, revolutions 55, boiler pressure 160° F. The temperature of the superheated steam had reached in one case 750° F. at the superheaters, and in another 700° F. at the engines, which in this case were of 1,000 I.H.P. of the vertical type, also with Corliss valves; but 500° to 550° F. was more usual. In no single instance, out of the large number of their Corliss engines in use with superheated steam had trouble of any description been noticed or reported in connection with the Corliss valves; and in only one instance had trouble been reported with the piston rings, which could fairly be ascribed to superheating. They had in fact been most agreeably surprised at the entire absence of any serious difficulties in connection with superheating, and they were recommending and supplying superheaters as a matter of routine, and quite beyond the experimental stag, with the majority of the engines and boilers they made. The results had, on the whole, been very gratifying, economies up to 30 per cent. having been reported, with simple engines working at 60 lbs., and over

23 per cent. with triple expansion engines at 200 lbs., whilst a compound engine with steam at 175 lbs. pressure superheated only 76° F. had given one I.H.P. for 11·1 lbs. of gross feed-water.

Mr. C. H. **Moberly** wrote that the author stated the case of superheated steam very clearly in its present stage of development. It was interesting to follow this development in Germany, where it has been extensively and successfully adopted in mills and factories, as has been shown by numerous articles in the "Zeitschrift des Vereines deutscher Ingenieure," namely :—

In 1894, page 737, a general description of the Schmidt system was given, and on page 828 Mr. Hunger described it more in detail, illustrating the vertical Schmidt boiler.

In 1895, page 5, began a detailed investigation of the system by Professor Schröter, followed by results of trials and illustrations of the Schmidt vertical boiler and engine.

In 1896, page 249, Professor Schröter gave the results of trials of a 1,500 H.P. triple-expansion engine and of other engines, showing the progressive improvements due to superheated steam; and on page 1245 he supplied a treatise on superheated steam-engines, with an illustration of the superheater between the cylinders. On page 1390 Professor Gutermuth gave results of trials of four different types of engines with superheated steam, with an illustration on page 1420 of a superheater applied to a Lancashire boiler.

In 1897, page 1402, Professor A. Seemann gave a full investigation of the superheated steam question, dealing also fully with the experiments of Professor Ripper of Sheffield. This was continued on pages 1433 and 1464.

In 1898, page 141, Professor Gutermuth again went into the question theoretically; and finally in 1899 Professor R. Dörfel summarised the subject, going very fully into the matter, illustrating the double-chamber cylindrical slide-valve referred to in Mr. Lenke's Paper, and giving an extensive table of results of trials of various types of engines, with and without superheated steam. These articles began on page 601 and were continued at intervals throughout the year; the last was on page 1518, dealing with low-pressure steam.

The following is a Memorandum of some of the Illustrations belonging to articles on Superheated Steam in the "Zeitschrift des Vereines deutscher Ingenieure":—

In 1894, page 828, Vertical Schmidt Boiler, with Paper by Mr. Hunger.

In 1895, page 6, Vertical Schmidt Boiler, larger scale, with Paper by M. Schröter.

In 1895, page 7, Schmidt Engine, Paper by M. Schröter.

In 1896, page 1248, Superheater between Cylinders, Paper by M. Schröter.

In 1896, page 1420, Lancashire Boiler with Superheater, Paper by M. Schröter.

In 1899, page 604, Double Chamber Cylindrical Valves for Superheated Steam, with Dörfel's Paper.

A PREMIUM SYSTEM OF REMUNERATING LABOUR.

By Mr. JAMES ROWAN, *Member*, of Glasgow.

Mr. Fred W. Taylor's Paper on the Premium System, published in *Cassier's Magazine* of October 1897, was probably the best of the many articles that had appeared on this subject, but the system described by him was not suitable for the purposes of marine-engine manufacture. To the ordinary piecework system there were the objections which were so well expressed by Mr. Slater Lewis in the *Engineering Magazine*,* namely :—

"It cannot be pretended, however, that the piecework system, as usually employed, commends itself as a satisfactory, still less as a final, solution of the problem. We obtain, it is true, an immediate definition and limitation of cost, coupled with a strong and direct inducement for the employee to exert his best endeavours to increase and intensify production. At least this is the theory; but in practice it is a true statement of the result only within very narrow limits. The defect of the method is, that when once the workman has begun to derive a profit from the transaction, the employer has no direct interest in his further exertions, but only the indirect advantage of a stationary labour-cost coupled with a greater intensity of output. The general result of this is, of course, well known and understood. There inevitably comes a time—if the workman continues to improve in skill, or to give evidence of a continuous and successful application of intelligence to his work—when the gains of the workmen appear excessive compared with his former earnings as a mere supplier of labour by the hour. The employer would be more than human who did not, at this stage, ask himself the question, ‘Have I not made a mistake in fixing prices?’

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* Vol. 18, 1899-1900, page 203.

“When this question is answered affirmatively, a reduction of rates inevitably follows. The suzerain power insists on remodelling the convention, and the result is frequently, not peace, but soreness. Of course, where much piecework is in vogue, the trouble does not necessarily arise with as much frequency as might be expected, for a very good reason. As soon as the workman finds himself approaching the point at which his extra earnings tend to rise beyond the limit at which the traditions of the shop teach him the reduction may be expected, his efforts slacken. He makes no endeavour either to improve in skill, or to trouble himself about little tricks for the better management and handling of his job. His interest for the future is barred, and the net result amounts to this, that he has adopted a somewhat greater intensity of production, and receives a somewhat greater constant remuneration than when he was on hourly wages.

“That there is a gain, both to man and employer, is obvious; but that it is a slight and limited gain is also obvious. Abstractly considered, the method is remarkable no less for what it wastes than for what it effects.

“From an examination of its defects we are enabled to formulate the conditions which must be fulfilled by a more satisfactory method. We require: (1) a minimum standard of remuneration based on the average attainments of hourly labour; (2) free and full incentive to the workman to improve upon this average, not merely up to a certain arbitrary stage of improvement, but without limit; (3) participation of interests between employer and workman in this improvement, not merely in its early stages, but to the ultimate extent to which the intensification of output and consequent reduction of costs per piece can be carried, either by constantly augmenting manipulative skill, or by a series of small improvements in method. A theoretically perfect system of remuneration should not involve the constant comparison between the piecework earnings of the exceptionally clever or skilful workman, and his former earnings when neither exceptional skill nor cleverness were asked for, nor sought to be rewarded.

"It may be objected that this theoretical perfection is actually realised to the full by the piecework system, if only we assume that rates shall never be cut. This is, of course, true; but it is not the whole truth. The element of participation by the employer in the direct reduction of labour-cost is entirely wanting, and that such participation is essential and just can be seen readily enough. If it be true that the actual reduction is wholly due to the efforts of skill or of intelligence exerted by the workman, it is equally true that the opportunity for such exertion is provided by the enterprise, and perfection of technical and business organisation of the firm."

With a view to the adoption of a reliable and satisfactory method of piecework, a Premium System was decided upon, of which the following is a description:—

Work, as recorded on a Job Ticket, Appendix I (pages 872–3), is given to a workman on a time allowance, and if he reduces this time allowance his rate of wages per hour, while he is working at the job, is increased by the same percentage as that by which the time allowance has been reduced. It is of course apparent that data must be collected for the purpose of arriving at the time to be allowed to do work. For this purpose a special department (Rate-fixing Department) is required, and when instituted, data accumulates very quickly. The period occupied in doing work under the usual time payment conditions may be accepted as the time allowance of the Premium System.

When a job is given to a workman, a Job Ticket is issued to him with a description of the work to be done and the time allowed to do it. On completion of the work the Job Ticket is initialled, and the time of day recorded on it by the foreman, and this is the time of commencing the next job. When the work has been examined and passed by the works inspector, the Job Ticket is handed to the Rate-fixing Department, which passes the same for payment. In the case of a job being rejected by the inspector, any premium which would otherwise have been earned by the workman, by reason of his having reduced the time allowance, is forfeited. No clerical labour devolves upon the workmen, and very little upon the foremen.

The time allowance for a job given to a workman rated at say 8d. per hour is 100 hours, and the actual time occupied on the job amounts to 75 hours. We have then 100 hours at 8d. = 800 pence against 75 hours at 8d. + 25 per cent. (2d.) = 750 pence, giving the workman a premium = 150 pence or 2d. per hour, and the employer a reduced cost = 50 pence. Provided the time allowances are equitable to employer and employed, and based on the average attainments of hourly labour, it will be evident from the foregoing that the higher the premium earned by the workman the greater will be the saving in cost. The output of the machines is also increased, but it is a hard matter to put a value to this.

Occasionally a piece of work is begun on one machine and finished on another. The Job Ticket in a case of this kind is passed by the first to the second operator, and so on until the work is completed, each workman engaged upon it receiving any premium earned, in proportion to the total reduction of time made in completing the whole job. Any number of men may be employed on the same piece of work, and it is not necessary that they should all remain at the work for the same period, because a slump time allowance is made to cover the time of all the men on a job, and the total time spent upon the job fixes the premium percentage, which is used in fixing the premiums of the different men only to the extent of the time each has been employed upon the work; that is, a job for which the time allowance is 1000 hours may be performed in 800 hours—one man might work 100, one 300, and one 400 hours. Each of these men would have his hourly rate increased to the extent of 20 per cent. for the time he had been employed upon the job. The reduction or increase of a workman's hourly rate is not affected, as any change in either of these directions made during the time he is engaged upon a job is calculated at a percentage on his hourly rate or rates. Neither is any difficulty introduced in respect to overtime allowances, as the actual time worked upon a job determines the time upon which a premium is paid. The overtime allowance, which in the Glasgow district is paid at the rate of 50 per cent. on the overtime worked, does not appear in the Job Ticket as time, being only shown as such in the Workmen's Time and Wages Book as a unit to fix the value of the overtime allowances. In the Job Ticket this allowance appears at its value in money. Nor is there any difficulty presented when working a night shift, as each of the two men at a machine receives a share of premium earned in proportion to the number of hours worked on the job.

It is advisable where at all possible that every man should work on his own account; but in cases such as before mentioned, which refer particularly to the Erecting Department, the inclusion of several men on one Job Ticket cannot very easily be avoided. It may be mentioned that in the Erecting Department the apprentices in their first year are not given a Job Ticket. In their second and third years they are junior apprentices, and half the time that they work is counted; in the fourth and fifth years they are senior apprentices, and three quarters of the time they work is counted. They are allowed the same time as a journeyman. In the Machine Department, apprentices in the fourth and fifth year do the same kind of work that is also done by journeymen, and they are allowed 25 per cent. more than journeymen.

The payment of premiums does not take effect until 5 per cent. premium has been earned, and thereafter only in multiples of 5 per cent. The original time fixed upon as a time allowance has never been reduced, unless there has been a radical change in the method of doing a piece of work. As a rule the premiums earned by the men have increased since the introduction of this system, sometimes due to the industry, skill, or intelligence exerted by the workman, but oftener due to those exercising a controlling power. The value of this premium system is not limited to a saving in cost of labour by the reduction of the time taken to do work. Numerous instances might be cited where the system has been the means of bringing to notice, through concentration of attention on its development, improved methods of manufacture.

Another feature to which special attention is directed is the use of the Job Progress Card, Appendix II (page 874). This card is prepared every morning by the Rate-fixing Department, and indicates the progress which has been made at the various machines; and it may be made of great value to employers and managers. The first column gives the machine numbers, the second column the hours allowed for the jobs in hand, the third column the number of pieces included in each job, the fourth column the hours spent upon the job in hand till 10.30 a.m. on the date the card is prepared, and the fifth column the previous records for similar jobs. The card is therefore an index of the progress of work in each and all machines in operation.

There is a Job Register Book, Appendix III (pages 875 to 878), for the Machine, Brass-finishing, Tinsmiths', and Smiths' Departments, Erecting in the Works, and Fitting on board the machinery in the Yard and at the Quay. As new jobs occur they are duly registered. Every separate job in the manufacture of a marine-engine, from the time the castings and forgings come into the works until the ship leaves after her trial trip, is registered in this Book.

The Job Data Book, Appendix IV (pages 879 to 882), is a record of the work done on each article, and this book now contains a most complete and miscellaneous collection of data in connection with the manufacture of marine-engines, and of other work. All whitewashing and painting, shifting of machines, laying down concrete floors, shifting of material from place to place, and many other operations for which, not so long ago, it would have been impossible to fix a time, are now recorded in the Job Data Book.

This system is by no means a final solution of the piecework problem, but it is submitted that this system is a step towards a solution. The value of good and powerful tools is forcibly brought forward, the use of jigs, gauges, etc., is found to be necessary, and old machines are placed at their true value. Meetings with managers and foremen for the discussion of questions arising in the course of manufacture are found to be necessary, and of great value. Better wages are earned by workmen, and more work and better work is got out of the machines. With this knowledge before us we do not hesitate to say that the introduction of a Premium System such as described would have an elevating influence upon any workshop where the hourly rate of pay or the ordinary piecework is in use.

Referring to the quotation from Mr. Slater Lewis' Paper (page 866), the following statements are answered.

(1) "A minimum standard of remuneration, based on the average attainments of hourly labour."

This statement is answered by the fact that no matter how long a man takes to do the work, whether from novelty, misfortune, misadventure, hanging over his work or carelessness, he receives his hourly rate of wages.

(2) "Free and full incentive to the workman to improve upon this average, not merely up to a certain arbitrary stage of improvement, but without limit."

This statement is answered very fully. If a man is repeating the same job on the same machine and continually reducing the time of production, by all means encourage this man to continue doing so.

(3) "Participation of interest between employer and employé in this improvement, not merely in its early stage but to the ultimate extent to which the intensification of output and consequent reduction of costs per piece can be carried, either by constantly augmenting manipulative skill or by a series of small improvements in method."

Statement No. 3 is almost a repetition of statement No. 2, and it may be added to the reply to No. 2 that if the time allowance has been fairly fixed at the beginning, the more a man earns the cheaper is the work; in other words, the element of participation is introduced.

[Note.—*The discussion on this Paper was combined with that of Mr. Thomson's and Messrs. Weir and Richmond's Papers, and commences on page* 907.]

APPENDIX I (*continued on opposite page*).

(Machine Dept.)

JOB TICKET. $\frac{1}{1}$

Contract No. 334. Mach. No. 193.

No.	Name.	Time Rate.	Hours.		Prem. Rate.	Premium.		
			Worked.	Prem.				
81	J. Gillan J.*	*d.* 8	21	21	4	.	7	0
						.	7	0

Time Saved 21 Hours = 50% No. off 1.

Main Engines: (389).

L. P. Crank shaft. Turning couplings and journals of crank. Complete.

Foreman: Wm. Wilson. Inspector: Jas. Adams.

Time Allowed 42 Hours.

Job Started 24th Aug. 1900, 8.45 a.m.

Job Finished 25th Aug. 1900, 8.0 a.m.

Lost Time Hours Overtime 12½ Hours.

Allowances 4*s.* 2*d.*

* Journeyman.

APPENDIX I (*concluded*).

(Fitting Dept.)

JOB TICKET. ⅓

Contract No. 334. Mach. No. .

No.	Name.	Time Rate.	Hours.		Prem. Rate.	Premium.		
			Worked.	Prem.				
		d.						
392	James Simpson. J.*	8	11	11	2·8		2	7
613	J. Brown. J. A.†	2	11¼	5½	·7			8
			22¼	16½			3	3

Time Saved 10½ Hours. 35% No. off 1.

Main Engines (46).

Crank Shaft: Shrink webs on to pins and coupling ends.

Driving in and dressing shaft, locking keys.

Foreman: J. Smith. Inspector: Jas. Adams.

Time Allowed 27 Hours.

Job Started 2 Aug. 1900, 6 a.m.

Job Finished 3 Aug. 1900, 7.30 a.m.

Lost Time J. S. ¼ Hours Overtime Hours.

Allowances .

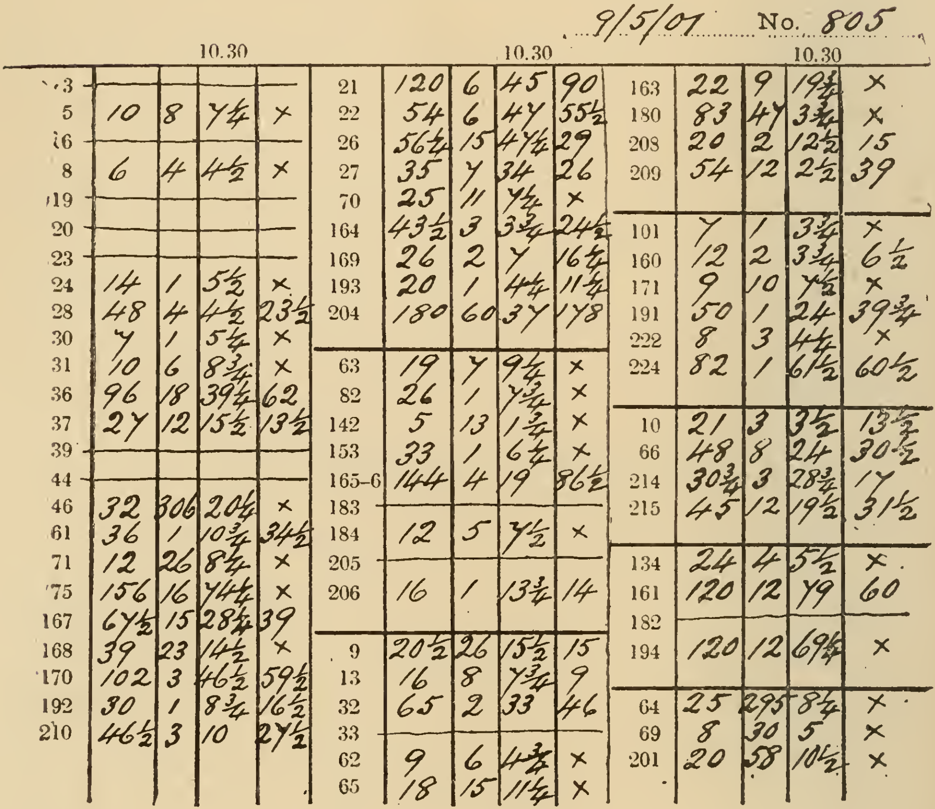
* Journeyman.

† Junior Apprentice.

APPENDIX II.

Fac-simile of Job Progress Card.

(Scale $\frac{13}{16}$th original. Ruled horizontal blue lines omitted.)



9/5/01 No. 805

			10.30	
3				
5	10	8	7¼	×
16				
8	6	4	4½	×
19				
20				
23				
24	14	1	5½	×
28	48	4	4½	23½
30	7	1	5¼	×
31	10	6	8¾	×
36	96	18	39¼	62
37	27	12	15½	13½
39				
44				
46	32	306	20¼	×
61	36	1	10¾	34½
71	12	26	8¼	×
75	156	16	74¼	×
167	67½	15	28¼	39
168	39	23	14½	×
170	102	3	46½	59½
192	30	1	8¾	16½
210	46½	3	10	27½

			10.30	
21	120	6	45	90
22	54	6	47	55½
26	56¼	15	47¼	29
27	35	7	34	26
70	25	11	7¼	×
164	43½	3	3¾	24½
169	26	2	7	16¼
193	20	1	4¼	11¼
204	180	60	37	178
63	19	7	9¼	×
82	26	1	7¾	×
142	5	13	1¾	×
153	33	1	6¼	×
165–6	144	4	19	86½
183				
184	12	5	7½	×
205				
206	16	1	13¾	14
9	20½	26	15½	15
13	16	8	7¾	9
32	65	2	33	46
33				
62	9	6	4¾	×
65	18	15	11¼	×

			10.30	
163	22	9	19¾	×
180	83	47	3¾	×
208	20	2	12½	15
209	54	12	2½	39
101	7	1	3¾	×
160	12	2	3¾	6½
171	9	10	7½	×
191	50	1	24	39¾
222	8	3	4¼	×
224	82	1	61½	60½
10	21	3	3½	13½
66	48	8	24	30½
214	30¾	3	28¾	17
215	45	12	19½	31½
134	24	4	5½	×
161	120	12	79	60
182				
194	120	12	69¼	×
64	25	295	8¼	×
69	8	30	5	×
201	20	58	10½	×

APPENDIX III (*continued on next page*).

JOB REGISTER.

(Machine Dept.)

Main Engines :—*PISTON AND CONNECTING-RODS.*

Connecting-Rods.

316. 1st Operation.—Turning complete.

317. 2nd Operation, Type "A".—Slotting outside flats of forks and sides of bottom butts.

318. 2nd Operation, Type "B".—Slotting sides of bottom butts.

319. 3rd Operation, Type "A".—Slotting round gudgeon.

320. 3rd Operation, Type "B".—Slotting flats of forked end.

321. Sawing out jaw.

322. Finishing jaw after sawing.

323. Boring out jaw and finishing.

324. 5th Operation, Type "A".—Slotting inside of jaw.

325. 5th Operation, Type "B".—Slotting inside of jaw and sides of top butts.

326. Boring out and finishing for gudgeon.

327. Boring out crosshead and crank-pin bolt-holes.

328. Boring oil holes in each connecting-rod.

APPENDIX III (*continued on opposite page*).

JOB REGISTER.

(Machine Dept.)

Main Engines :—*CRANK-SHAFT.*

389. Crank-shaft. Turning couplings and journals of crank complete.

390. Boring and rough-widening holes in two couplings and facing holes in one. Boring two steady pin-holes.

391. Boring holes for eccentric pulley keyseats.

392. Crank ends. Boring holes through centre.

393. Round key for crank-shaft.
Turning to fit and tapering point.

394. Boring holes for round keys and boring off centre.

395. Cutting into two pieces.

396. Boring two couplings, widening and facing one.

397. Boring two steady pin holes.

398. Boring two couplings and facing two.

399. Boring and facing one coupling.

APPENDIX III (*continued on next page*).

JOB REGISTER.

(Fitting Dept.)

Main Engines :—*PROPELLER-SHAFT.*

9. Shrinking liners on propeller-shaft.

10. Cutting keyway in propeller-shaft and fitting key.

11. Tapping holes and pinning liners on propeller-shaft. Fitting nut and stoppers to propeller-shaft.

12. Bolting together steel couplings with black bolts.

13. Cutting sheet-iron liners for muff couplings.

14. Wrapping propeller-shaft between liners with canvas and marline.

15. Tapping hole in liner and fitting cock.

Pumping in boiled oil and plugging up holes again.

16. Cutting clearance for slotting out propeller-shaft keyway.

APPENDIX III (*concluded from page* 875).

JOB REGISTER.

(Fitting Dept.)

Main Engines :—*CRANK-SHAFT*.

46. Shrinking webs on to pin and coupling ends.
Driving in and dressing shaft locking keys.

47. Boring holes for crank-pin locking keys.

48. Driving in and dressing crank-pin keys.

49. Dressing corners of webs.

50. Polishing webs.

51. Setting up cranks, and marking off holes in couplings.

52. Setting up cranks, and widening holes in couplings.

53. Chipping off centres of coupling-bolts.

54. Labourers widening holes in coupling of crank-shaft.

55. Bedding dummy shaft to place, chipping gutters in main bearing bushes.

56. Bedding crank-shaft to place complete and fastening all main bearing top nuts and pin and taking leads.

57. Making and fitting Board of Trade gauge to crank-shaft.

APPENDIX IV (*continued to page* 882).

Job Data Book, Machine Department.

(Scale half-size. Ruled horizontal blue lines omitted.)

334

389 Turning Complete

PART OF ENGINE. Crank Shaft

OPERATION. Turning & Finishing Complete

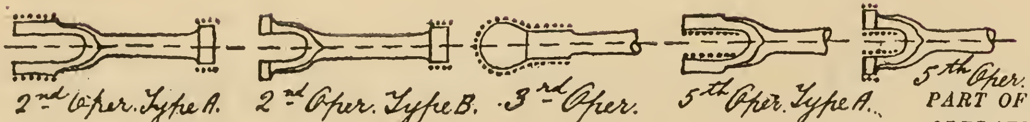
Engine No.	No. of Pieces.	Date. In.	Date. Out.	Time Allowed.	Time Taken.	Details of Operation	Remarks.	Class Mark.	Operator	Machine No.
	1900									
Jobbing 398	1	23/3	24/3	40	23½		Job 389	11	D. Stewart	193
333	1	5/4	10/4	50	25½		" 389	11	Gillam	193
331	1	31/3	5/4	50	15½		" 389	11	Stewart	193
Jobbing 387	1	10/4	13/4	46	25		" 389	11	Gillam	193
Jobbing 402	1	4/4	5/4	30	14½	Roughing body.	Solid Crank	111	J. Ayton	140
330	1	19/4	24/4	50	29½		Job 389	11	Gillam	193
330	1	13/4	19/4	50	25		" 389 L.P.	111	Gillam	193
332	1	5/6	8/6	50	32½		" 389	11	Gillam	193
332	1	8/6	12/6	50	27½		" 389	11	Gillam	193
332	1	13/6	15/6	50	24½		" 389	11	Do	193
333	1	12/6	15/6	50	24½		" 389	111	Do	193
1 Spare 335	3	16/5	23/5	92	46		" 389 Steel	11	Do	193
Jobbing 402	1	20/6	23/6	60	39		" 389	11	Do	193
333	1	23/6	26/6	50	25		" 389	11	Do	193
Jobbing 467	1	26/7	27/7	35	21½		" 389	11	Stewart	3
Jobbing 467	3	7/7	10/7	28	22	Rough turning & finishing for web	2 Cranks & 1 Ford Piece	=	Carney App	36
336	1	4/8	7/8	33	15½		Job 389	11	Gillam	193
337	1	10/8	13/8	33	15		" 389	111	Do	193
337	1	14/8	15/8	33	15½		" 389	11	Do	193
336	1	8/8	10/8	33	15½		" 389	11	Do	193
336	1	7/8	8/8	33	15½		" 389	11	Do	193
337	1	10/8	15/8	33	15½		" 389	11	Do	193
333	1	2/8	4/8	50	27		" 389	11	Do	193

etc. etc. etc.

APPENDIX IV (*continued on opposite page*).

Job Data Book, Machine Department.

(Scale half-size. Ruled horizontal blue lines omitted.)



335

PART OF ENGINE. Connecting Rods

OPERATION. Slotting

Engine No.	No. of Pieces.	Date. In.	Date. Out.	Time Allowed.	Time Taken.	Details of Operation.	Remarks.	Class Mark.	Operator.	Machine No.
	1900									
330	3	8/2	3/3	:90	63	2nd & 3rd Operation	Job 318. 320.	11	Ritchie	160
330-1-2 14	9	3/1	15/3	135	87	5th Operation	" 325.	III	Do.	160
335	4	12/4	14/4	20	17½	2nd Operation	" 317.	1	Do.	160
333	3	2/4	11/4	90	69½	2nd & 3rd Operation	" 318. 320	11	Do.	160
334	3	14/4	19/4	30	23¼	2nd Operation	" 317	11	Do	160
334.	3	19/4	26/4	64½	48½	3rd Operation	" 319	11	Do	160
333	3	3/5	7/5	45	29	5th Operation	" 325	111	Do	160
334 1 Spare	3	28/4	3/5	48	36	5th Operation	" 324	11	Do.	160
335	4	5/5	14/5	64	47	3rd Operation	" 319	11	Airlie	47
336 1 Spare	2	17/5	22/5	48	26½	2nd & 3rd Operation	" 318 320	11	Ritchie	160
335 1 Spare	4	1/6	4/6	24	16	5th Operation	" 324	11	Airlie	47
335	4	30/5	7/6	20	14	Sawing out jaw	" 321	11	Fraser	194
336	1	9/8	15/8	24	16	2nd & 3rd Operation	" 318. 320	11	Ritchie	160
337	3	16/8	24/8	72	47½	2nd & 3rd Operation	" 318. 320	11	Do.	160
336	3	15/8	20/8	27	16½	5th Operation	" 325	11	Do	160
324 & 334	2	30/8	4/9	20	18½	2nd Operation	" 317	1	Do	160
337	3	8/9	12/9	21	19½	5th Operation	" 325	1	Do.	160
324 & 334	2	4/9	7/9	43	35½	3rd Operation	" 319	11	Do.	160
324 & 334	2	19/9	21/9	20	17½	Sawing out jaw	" 321	1	Fraser	194
336	2	7/7	9/7	13	14½	" " "	" 321	III	Do	194
337	3	24/8	29/8	10	27½	" " "	" 321	11	Do.	194
324 & 334	2	20/9	21/9	16	14½	Finishing jaw already sawn out	" 322	—	Ritchie	160
W.R.O.33	2	10/10	11/10	20	17½	2nd Operation	" 317	1	Airlie	47
					etc.	etc.	etc.			

APPENDIX IV (*continued on next page*).

Job Data Book. Fitting Department.

(Scale half-size. Ruled horizontal blue lines omitted.)

PART OF ENG., Propeller Shaft 434
OPERATION, Fitting

9 Shrinking liners on propeller shaft
10 Cutting keyseat in shaft + fitting key.
11. Tapping holes + pinning liners on shaft fitting nut + stoppers to shaft
12. Bolting together steel couplings with black bolts

Eng. No.	Date Finished.	Hrs. Allowed.	Hours Taken.						Prem. Time.	%.	Workmen's Nos.	Job Line No.	Job No.	Class Mark.	Remarks.
			Jour.	S. App.	J. App.	Boys.	Labs.	Total.							
325 Spare	7/5/00	5	4					4	4	20	381.	287/15	11	$\overline{III}$	
325 Spare	7/5/00	3½	2¼					2¼	2¼	35	381	287/23			Fitting in key + cutting off centre.
331	8/5/00	55	38¼	15¾				54	50	8	371. 381. 303. 387.	287/24	10·11	I	
331	9/5/00	4½	2	2				4	3½	12	381 571.	287/66		$\overline{III}$	Tapping 1 7/8 hole, thro nut
335	19/6/00	20	25	2				27	26½		381 667.	290/46	10	$\overline{III}$.	
Jobbing 387	24/5/00	55	19¾	19¾				39½	34¾	36	381 571	286/59	10 11	$\overline{III}$	
331 Spare	26/5/00	4½	2½					2½	2½	44	381			$\overline{III}$	Tapping 1·7/8 hole thro' nut
331 "	25/5/00	55	14	16½				30½	26½	51	381 571.	286/82	10.11	$\overline{III}$	
1.	8/6/00	116	92½					92½	92½	20	265	500/21	10	II	
330	2/7/00	55	37½					37½	37½	31	381	307/49	10-11	II	
332 Spare	7/7/00	3¾	3¾					3¾	3¾		388	309/83		$\overline{III}$.	Trying shaft into boss + marking off and tapping 1 7/8" hole thro' nut.
332. "	3/8/00	59½	16¼		16½			32¾	24¼	59.	381 619	310/46	10·11	$\overline{III}$	
324 "	31/7/00	55	18		18			36	27	50.	381 619	311/3	10.11.	III	
335 "	11/8/00	20	10					10	10	50	381	325/70	10-11	$\overline{III}$.	
336.	19/9/00	13	8		8.			16	12	7	382 608 621	343/19	14.	$\overline{III}$	
Jobbing 31	28/11/00	55	15½	15½				31	27¼	50	381. 566.	363/95	10 11	III	
Jobbing. 20	24/10/00	42	13¼		13¼			26½	19¾	53	381. 615	361/34	10·11	III	
323 Spare	20/10/00	55	15	15				30	26¼	52	381 566	344/81	10 11	III	
Jobbing 16	2/10/00	27	18		18			36	27.		382 615	344/80	14	$\overline{\cdot}$	
334. Spare	1/10/00	55	15	15				30	26¼	52	381. 566	344/55	10 11	III	
334	28/9/00	55	21½	6¾				28¼	27	51	381 566	344/6	10 11	III	
333	19/9/00	55	44¼	14¾				59	55¼		381. 566	341/33	10 11	=	
333. Spare	15/9/00	55	27¼	5½				32¾	31½	42	381 561	341/21	10·11	II	
336	19/9/00	45	13¼	13¼				26½	23¼	48	393 566	343/5	10 11	$\overline{III}$	
337	18/9/00	45	16	16				32	28	37	393 566	342/67	10 11	II	

etc. etc. etc.

APPENDIX IV (*concluded from page* 879).

Job Data Book, Fitting Department.

(Scale half-size. Ruled horizontal blue lines omitted.)

461 46 Shrinking webs on to pin and coupling ends. Drawing and dressing shaft locking keys.

PART OF ENG., Crank Shaft.
OPERATION, Fitting.

Eng No.	Date Finished.	Hrs. Allowed.	Hours Taken. Jour.	Hours Taken. S. App.	Hours Taken. J. App.	Hours Taken. Boys.	Hours Taken. Labs.	Hours Taken. Total.	Prem. Time.	%.	Workmen's Nos.	Job Line No.	Job No.	Class Mark.	Remarks.
331.	30·3·00	132	104¼		44¾			149	126½	4	298. 462 425 405.	253·23	46.	—	4 Cranks. (1 Spare).
330.	12·4·00	99	47¾		4¾			52½	50¼	49	298. 462.	269·70	46.	III	3 do.
335 Spare.	25·4·00	40	19½		16½			36	27¾	30	298. 458.	273·4	46	II	3 Cranks in 1 piece.
332.	13·6·00	33	22¼		13.			35¼	28¾	13	392. 607.	289·87	46.	I	1 Crank.
332.	5·5·00	66	51¾		52½			104¼	78.		392. 607.	288·29.	46	=	2 do.
333.	7·6·00.	33	15.		12¼			27¼	21.	36	392. 607.	289·65.	46	II	1 do.
336	26·6·00	64½	34¼		31¾			66	50¼	21	392. 573	290 77	46	III	3 do.
333.	31·7·00	33.	15¾		16¾			31¼	24	29.	392 613.	310·99	46.	II.	1 do.
334.	3·8·00	27.	11.		11¼			22¼	16½	38	392 613.	311·32	46.	III	1 do.
337.	2·8·00	64½	27		27.			54	40½	35	392. 613.	311·6	46.	III	3 do.
Jobbing 402.	27·7·00	18	10½		10½			21	15¾	12	392. 613	310·77			Shrinking 2 webs on to Crank Shaft.
" 467.	26·7·00	28½	20¼		19¾			40	30¼		392·613.	310·38	46.	—	3 Cranks in 1 piece
" 468.	17·8·00	21.	7¾		7¾			15½	11¾	44	392 613.	326·42	46.	III.	1 Crank.
336·7. Spare	10·8·00	43.	19¼		20.			39¼	29¼	30	392·613.	226·51.	46.	II.	2 do.
334.	21·8·00	54	23½		23½			47.	35¼	34	392. 613	327·1	46	III	2 do.
W.O. 333.	26·10·00	43	26½		24.			50½	38½	10.	392·613.	361·12	46	I.	2 do (Extra Work 4 hrs)
Jobbing 4.	5·10·00.	32	14.		14.			28.	21.	34	392 : 613.	346·30	46.	III.	3 Cranks in 1 piece.
340.	27·11·00	99	58½	3½	53½			115½	88	11.	392.574.607	363·48	46	I.	3 Cranks.
343-4	6·12·00	150	59½		55½			115	87¼	42	392.613.607 636	366·4	46.	III.	6 do.
338.	13·12·00	35.	15¼	7¼	8¼			30¾	24¾	29	392 559 607.	364·66	46	III	1 do.
338.	25·1·01.	70	44	1¼	30¾			76.	60½	14	392 567 604 607	364·71	46	II	2 do.
339·41.	24·4·01	33	10¼		10¼			20½	15½	53	392 630.	441·13	46	III.	1 do.
1339·41.	15·4·01	165	63¾		69¾			133½	98¾	40	392 602 644	444·8	46	II	5 do.

SOME FACTORS AFFECTING THE ECONOMICAL MANUFACTURE OF MARINE-ENGINES.

By Mr. WILLIAM THOMSON, of Glasgow.

The most desultory reader of our technical journals cannot fail to be struck with the great and increasing interest which has of late years been taken in the internal economy of our engineering workshops. The object of this Paper is to draw special attention to certain factors affecting this economy, which have hitherto not received the consideration that their importance warrants. Into the subject of commercial organisation of engine works, or the strictly on-cost factors, it is not intended to enter, but instead, to touch upon certain factors, which directly affect the workshop itself, and have a distinct influence upon its productive capacity. The interest which is spreading in regard to workshop economies is one of the most hopeful signs that an awakening to the new order of things is taking place. Manufacturers are becoming alive to the fact that it is necessary nowadays for a closer and more personal interest to be taken in the minutest and, apparently, most trivial details of workshop practice, and are forced to consider certain influences, some of which have been looked upon as outside the range of practical workshop economics, or at most have received a qualified or indifferent approval.

There is a wide and interesting field in every workshop for him who makes these his special study, but it requires continuous and concentrated attention to obtain the best results. The points particularly referred to are—

(1) A premium system of labour remuneration.
(2) Good, accurate, and powerful tools.
(3) Arrangement of tools and roomy shops.
(4) Clean and tidy shops.
(5) Well lighted and well warmed shops.
(6) Standardisation.

The Premium System.—The first and greatest of all these influences is the introduction of the Premium System, which effects nothing short of a complete revolution in a shop, and its consequences are very wide and far reaching indeed, and in directions which at first sight might seem to have no connection with the source.

One of the primary results of the premium system is the establishment of accurate data, upon which comparisons can be based and deductions made. It is hardly possible to overestimate the benefits of having accurate and reliable detailed data in the works as a means of comparison, yet this is often overlooked or ignored, and the comparatively small sum per annum, which the establishment of an efficient time or records office in the works would cost, is grudged, because the profitable return which such an investment would give, if properly worked and managed, is not realised.

The revelations, which would be made by the introduction of such an office in any place previously without one, would be sufficiently convincing to most engine builders, yet lethargy or indifference keeps many from availing themselves of a means of speedily infusing new vitality into their place, and starting afresh with renewed youth and vigour. There is no doubt that it requires an amount of faith and the whole-souled energetic personal attention of a principal or highly-placed official to introduce such a system. The necessary work takes a large amount of time for a considerable period, but the results are worth it all, and once the system is started and in fair working order there will be no looking back. Table 1 (page 886), columns 1 and 2, gives a few examples of what the premium system has done in the way of economising time.

Apart, however, from the question of economising time, the system provides an admirable and efficient check upon any excessive rise in wages cost, as each contributory cause becomes apparent, and can be investigated the moment it arises, and suitable means taken to prevent a recurrence in future. The knowledge that such variations above the normal in the time taken are investigated in detail and checked, acts in a most wholesome manner upon the men and foremen, keeping them alert and tending to produce an even and gradually increasing average of performance.

Accurate and Powerful Tools.—Another most important factor in the economical production of work, is good, powerful, and, very especially, accurate machine tools. This is axiomatic. Everyone acknowledges this, but how many builders even yet realise exactly what this means, or can state in reliable figures the actual difference between one tool and another in output, which, after all, is the real basis of comparison. Had they been able to do so, the wave of revival and re-organisation now setting in would have commenced far earlier than it has done, and a vague and hesitating belief in the need for new and up-to-date tools gradually taking the place of a hitherto blind confidence in old and cherished machinery, would have speedily grown into strong conviction, when backed by the hard facts of accurate and reliable data of comparison.

The experience of the author's firm in this direction has been one of considerable extent. Old tools which were formerly thought to be doing fairly good or average work on the whole were found to be hopelessly wanting in speed, handiness, and principally accuracy and power; within the last few years nearly the whole of these machine tools have been sold or otherwise disposed of, and new and more powerful machinery substituted.

The Premium System had not been very long started before it began to show up some very great discrepancies in the performance of

TABLE 1.

Description of Work.	Same Machines throughout.			
	(1) Time taken under old Time System.	(2) Time taken on introduction of Premium System.	(3) Time taken in better location with greater facilities.	(4) Record time for the same job.
	hours.	hours.	hours.	hours.
1. Turning conn. rod. 1 off.	43½	36	35	29¼
2. Slotting conn. rods. 3 off.	31	24½	22¼	20
3. Crank webs (finishing holes. 1 off).	7⅔	5¼	4¾	3½

	Old Machines under		New and more powerful Machines (on Premium System).	
	Old Time System.	Premium System.	First time on new Machine.	Record Time.
	hours.	hours.	hours.	hours.
4. Turning tunnel shafting. 1 off.	42	29¾	23½	21
5. Turning ecc. rods. 1 off.	22	11½	9	8¼
6. Turning thrust shaft. 1 off.	129	97¼	75	65
7. Finish turning crank shaft. 1 off.	42	34	15	9¾
8. Turning quad. blocks. 13 off.	195	140	91¼	90½
9. Slotting sole-plates. 1 off.	70	59¼	41½	35¼
10. Slotting condenser. 1 off.	64	56	44	34
11. Slotting H.P. cylinder. 1 off.	45¾	33¾	24	21
12. Ripping out holes in crank webs (1 web). 2 holes.	29	17	9	7
14. Hole-boring main bearing covers for bolts. 12 holes.	45	37	27¼	20
15. Planing six steel slabs for 12 crank webs.	142½	102	65¼	65¼

similar tools when on the same work. This led to an investigation of the causes, and generally it was found that the result was due to the weakness or want of power of the less efficient tool. Indeed, so frequently was this particular fault of weakness or want of power found to exist, that the limit of output was very soon reached, and in order to overcome this, all the work had to be moved up a stage or two, and a heavier class of tool used, in order to get more power for the heavy cutting, which the Premium System developed. This led to congestion in the work for the heaviest tools, so newer and more powerful ones all along the line were substituted as soon as possible. A few examples of the results of this substitution are given in Table 1, by comparing columns 2 and 3.

The high cutting-speeds, which have lately been introduced since the Bethlehem Company raised the question, have very much increased the stress on lathes and boring machines, and have rendered powerful and substantial machines a greater necessity than ever. Generally speaking, in machines of this class cutting power is not in proportion to capacity, and want of belt power is a fault more often met with than not in machines of all classes. A certain tool made by a first-class firm was purchased by the author's firm three years ago, and after repeated trials it was concluded that it had not adequate belt power, so when a second machine was ordered, an increase in the ratio of gearing of about 28 to 30 per cent. was insisted upon, much against the will of the toolmakers, who considered that the first machine was amply powerful. The result is that the newer machine turns out the same work as the old in 26·5 per cent. less time.

Arrangement of Tools and Roomy Shops.—The questions of arrangement of tools and roomy shops are closely connected and interdependent, and where these have to be applied to existing buildings they become very difficult ones to settle; in most cases the result cannot be anything more than a compromise, because, for a given sequence of operations to be carried on within a given crane area, certain tools are required, and roominess around each tool cannot be given without affecting the arrangement of the tools, probably to the extent of excluding some of them altogether from the building, and thus breaking the sequence of operations by extra handling. When, however, new shops or extensive alterations are about to be entered upon, the question deserves the most serious consideration. The comfort and convenience of having roomy machine shops is another condition very difficult to put a money value upon; but those who have had to deal with overcrowded machine shops, where a large proportion of floor space is taken up by tools or by the work for them, realise the great inconvenience and discomfort caused by this, and must see that money is being lost under such an arrangement. Plenty of room should be allowed round each tool, and this applies in a greater degree to heavy machine-tools than to light, because these have to deal with much heavier and more bulky pieces which cannot be easily handled or transported from spot to spot, and are generally stacked around or near the machines which operate on them.

The question of handling of material, which is the direct result of the arrangement of tools, is one which has not received the attention it deserves, simply on account of the difficulty of getting at the direct loss caused by a poor arrangement, even if it is realised that a loss is taking place; and experiments are tedious and expensive. There is no doubt, however, that much can be done in this direction in the marine-engine shop, if these questions be properly investigated.

As an example of what can be done by the consideration of these questions, it might be mentioned that after the author's firm laid down their new boiler shop, the work turned out by the light and heavy plating squads was done in 19·6 per cent. less time in the new shops than it had averaged in the old, while the machines turned out their work in 10 per cent. less time than before; the conditions in both cases as regards tools and appliances being exactly the same, except that more room was allowed.

Another example taken from the machine shop illustrates this same point very well. A group of three machines was located in the old machine shop in somewhat cramped and inconvenient positions, but afterwards these machines were shifted to a new machine-shop and given ample room. The results of this new arrangement are given below in Table 2 :—

TABLE 2.

Machine.	Saving.		Output increased by
	Time.	Money.	
	per cent.	per cent.	per cent.
Double-headed Horizontal Borer.	3·9	2·5	4
H. and V. Planer . .	22·5	14	29
Connecting-rod Lathe. .	12·8	8·3	14·7

In this comparison the conditions were as nearly as possible the same in both cases; the machines doing the same kind of work, the same men were at the machines, and were working under the premium system in the new shop as in the old. The result was that the men made on an average—which is taken over a long period in both cases —9·3 per cent. more wages, the work was 8·3 per cent. cheaper to the firm, and 15·9 per cent. more work was got out of the same machines, due entirely to a better arrangement and more roomy location of these machines. This example is only one of many which could be given, but serves to bring out the points which have been mentioned.

Clean and Tidy Shops.—With regard to clean and tidy shops it is the belief of the author's firm—and they are encouraged in this by experience and example of the most progressive shops—that these do pay; yet are not dirty, dark, untidy, cold and badly arranged shops met with in this and other countries, turning out good work, which must cost, and is costing, more than it might, simply on account of these drawbacks. That such conditions are allowed to continue is due either to indifference or ignorance of better, on the part of the responsible management, or if they realise the benefits of having better conditions, they lack the necessary courage or perseverance to put an end to the old bad ones. The value of having clean, tidy, well-lighted and warmed workshops is one which it is impossible to determine in money, but that it does have an actual and very real and substantial value is the belief and experience of all those who have embodied these conditions in their workshop practice, and there are now many examples of this belief.

One cannot have a clean shop which is not a tidy shop, and neither will be found in a badly-lighted shop. The author's firm set out to improve on these lines by first getting rid of the old earthen floor which is so common, and by laying the whole of the ground floor with granolithic and concrete pavement. The improvement is most marked; formerly with the old earthen and iron-chip floor it was impossible to keep anything clean. Dirt and dust were the order of the day if the floor had to be swept, so it was generally left alone as long as it could be tolerated. Now there is no trouble, but instead a fine, smooth, clean, bright surface to move about on. The floor is from 9 inches to 12 inches thick in most places, and below machines somewhat thicker, and consists of about 2 inches of rough bottoming of broken stone, then 6 inches of concrete of 5 to 1, and a top finish 2 inches thick of facing made of granite chips and cement in the proportion of 1½ to 1. As it sets, it is levelled and smoothed off with a trowel and in three days is ready for use, becoming quite hard in about a week, and when thoroughly set the floor assumes a beautiful white surface which has the effect of reflecting the light and perceptibly aiding the general lighting of the shop. Although somewhat dearer than other styles of flooring, there is none other which possesses so many advantages. It has a fine, bright, smooth surface, and is therefore easily swept and kept clean, is easily repaired, and does not wear into hollows like wood paving, and there has been no complaint from the workmen about it being sore to the feet.

Well Lighted and Well Warmed Shops.—The benefits of having a well lighted engine and boiler shop are pretty generally recognised, but not to the extent they might be. There are still far too many places—some of them of first rank—without adequate means of lighting, struggling along with lucigen lamps or gas in an almost Stygian darkness, which can only be dispelled by electric light and plenty of it. This is more generally the case in boiler shops than in machine shops, and, if there is a place where there ought to be good light, it is in a boiler shop. The amount of time lost by men cautiously feeling their way about in semi-darkness, coupled with the time lost by skulkers and loafers dawdling away their time in dark corners, is very considerable; besides which, men very naturally dislike having to work in a dark shop, and their unwillingness affects their attendance, and they lose time.

Owing to certain circumstances the new boiler shop electric light installation was not in working order until the winter season was half through, yet from the day the current was switched on the boilermakers' attendance improved, and, while the average time lost before the introduction of electric lighting was 14·72 per cent., after the light was introduced the time lost averaged 13·2 per cent., a distinct saving of over 1·5 per cent., or three-quarters of an hour per week per man. This is attributed solely to the lighting of the shop. The difference in other directions is most marked. The men can move about with freedom and decision, there are no dark corners, the time workers have not the same temptation to waste their time, and managers and foremen can see what is going on from end to end of the shop with the utmost distinctness. Table 3 (page 892) gives a comparative statement of the various shop lighting.

With regard to the warming, this is a problem which has given the firm much thought for some time back, but as yet no definite decision has been come to in the matter. The range of temperature is not nearly so great in this country as in the United States and Germany, and the want of proper heating facilities does not become one of daily experience, hence probably the reason why so little has been done in this direction. Nevertheless, there cannot be any doubt that as a rule engineering workshops in this country fall very short in this direction. The idea which used to be very prevalent, especially in boiler-making lines, that a cold snap made men work all the harder in order to keep themselves warm, is happily exploded, and a more rational view is now being taken of this hitherto much neglected subject. How is it to be expected that work, and especially good work, is to be got from men whose hands are chilled to the bone, and while the main energies are naturally taken up with means of keeping up their circulation.

TABLE 3.

Shop.	Area.	Lights.	Amount of floor space per ampère.
	sq. yards.	ampères per pair.	sq. yards.
Boiler Shop . .	3700	22 at 10 4 at 15	13·2
Heavy Machine Shop C. I. Bay.	880	12 at 10	7·3
Light Machine Shop C. I. Bay.	835·5	11 at 10	7·6
Erecting Shop . .	1040	11 at 10	9·4
Heavy Machine Shop M. I. Bay.	1430	12 at 10	11·9
Heavy Machine Shop M. I. Bay Gallery (Screwing Gallery).	479	4 at 10	11·9
Finishing Shop .	574	12 at 10 (inverted)	4·8
Smithy . . .	511	4 at 10 (inverted)	12·7

Voltage 110. Körting and Mathieson.

Standardisation.—The Premium System, with its attendant records, very soon showed up the benefits of having duplicate work, as the saving of time was quite considerable where a run of duplicate or nearly similar pieces was given to a machinist. This was so marked that the question of standardising, not only the details, but the whole engine, was gone into, in order to get the full benefit of this, and as patterns began to require renewal the engine was redesigned with this end in view. In carrying out this idea in a new design it was found necessary, not only to consider the engine and its details in relation to themselves alone, but also with special regard to their position in the range of sizes which it was decided to make, with a view of keeping down the number of different sizes of details. The question instantly became one not only affecting the whole range of engines made by the firm, but also their practice in connection therewith. This practically meant redesigning simultaneously all the sizes of engines made; but a careful analysis and consideration of the requirements to be met enabled the whole range to be suitably broken up into well defined groups, each group representing a certain size of main centres and permitting certain variations of cylinder diameter and stroke within well defined limits, and suitable for the usual steam-pressures. The details—which in each group are never altered although the cylinders may vary within the group limits—are in very many cases common to several groups, and a large number common to the whole range. This object is always kept in view, in order to provide as much duplicate work as possible. Especially is this so in the case of the very small and numerous details, because in these the governing factor in the cost is the wages, not the material; a slight and unimportant variation in size causes a relatively large variation in wages cost, while in the larger details the conditions are reversed and the material becomes the important cost factor, a relatively small variation in wages covering a very large variation in size. The location of the dividing line between these two conflicting sets of conditions thus becomes a matter of considerable importance, but the accurate data from the time-office enables its position to be fixed with great exactness, so as to allow of as much duplication of parts as will pay.

When, however, duplication of pieces can no longer be carried out on account of the cost of material prohibiting it, much can be done in the way of duplicating similar machined, faced, etc. parts, in different groups. This enables and encourages the use of jigs, which, under other conditions, would not have been warranted by the saving in wages. When even this cannot be done, standardisation by a graded series of similar pieces does much to make the progress of the work through the drawing office and the shops easy and free from the friction and delay incidental to sudden and abrupt changes in design. In the drawing office it has the effect of crystallising that vague thing known as "our practice," and compels it to carry out its work on well defined lines, thus avoiding expensive and irritating changes and mistakes or oversight. It has also the effect of economising draughtsmen's time, as a standard series of drawings once properly arranged do not require to be redrawn for every new job.

In the shops, standardisation by its consistency in design familiarises the staff and men with the practice, and enables them to go about each new job with confidence and expedition, knowing that each job as it comes forward, if not a duplicate, will at least be similar, all of which go far to speed up the progress of work through the shop and thus increase the output. And above all, by the very fact that the means to effect this calls for the best facilities and most exact workmanship, the result is that the character of the workmanship is raised besides being cheapened, with satisfactory results to both consumer and manufacturer.

[NOTE.—*The discussion on this Paper was combined with that of Mr. Rowan's and Messrs. Weir and Richmond's Papers, and commences on page* 907.]

WORKSHOP METHODS: SOME EFFICIENCY FACTORS IN AN ENGINEERING BUSINESS.

By Messrs. WILLIAM WEIR and J. R. RICHMOND, of Glasgow.

Summary.

The Paper gives an account of several schemes, which have been inaugurated by the authors, to interest the staff and men in securing greater efficiency in the shops of an engineering establishment. Brief descriptions are given of the working and general results of:—

I. The Premium System.
II. A Foreman's Club, for the discussion and settlement of shop problems.
III. A Suggestion Scheme, whereby monthly awards are given to the employees for the best suggestions leading to improvements.
IV. A Technical Committee, for dealing with new designs and experimental work, and for the systematic consideration of complaints and defects.
V. An Intelligence Department, for the collection of data on particular subjects, for the use of various departments in the works.

So many papers have been written, and so much literature now exists on the equipment and organisation of engineering works, that a brief consideration of some less frequently treated factors in promoting efficiency in the shops may be of interest and possibly of value. No claim to novelty is made on behalf of these schemes, as several of them are of trans-Atlantic origin, but their success when transplanted to this side shows that much can be done to interest the men and the staff generally in their work, and to stimulate the initiation of improvements. It is as true to-day as when John Stuart Mill wrote that "Capitalists are almost as much interested as labourers in placing the operations of industry on such a footing, that those who labour for them may feel the same interest in the work, which is felt by those who labour on their own account"; in fact, the greater division of labour and specialisation of product, which are the features of modern shops, require not only improved environment for the workers, but also some additional stimulus apart from the daily round, to promote a live and healthy spirit, if a high grade of efficiency is to be kept up in an establishment.

The schemes to be described have now been in operation for some time, so that a fair idea can be given of their working results, and it is the experience of the authors, that, when judiciously introduced and governed by common-sense principles, they furnish most valuable assistance in the conduct of business. The descriptions of the various efficiency factors following are not intended to be exhaustive, but rather suggestive sketches embodying practical points which experience has shown to be essential.

(I.) *Premium System of Remunerating Labour.*—In an engineering works which for many years has worked with only time wages, workmen who have been employed for a long period in the establishment obtain generally a higher hourly rate than workmen who have only been employed for a comparatively short period, due to their supposed better acquaintance with the work; but in many cases younger and fresher men are better and more productive men than the "old timers," so that the relative wages do not represent the relative values of the men.

To remedy this state of affairs and to obtain a system whereby every man receives the same standard rate of wages, and in addition, an extra remuneration for any increase over a normal basis rate of production, it was decided, after considering all the best known systems of remuneration, to adopt the Premium System, for the following reasons:—

(1) The system was simple in its conception and easily understood by the men, their extra remuneration being easily calculated by themselves; the differential rate system was open to objection on this point and tended to lead to friction between the men and the administrators of the system.

(2) The system was comparatively simple in its application, and did not involve a very large additional staff. In the works in question about 500 men work under premium, and the staff numbers 5 men and 2 boys, including the superintendent.

(3) It had not the defect of piece-work, that an error in rate fixing is either expensive or discouraging. An error in premium rate fixing affects only the *premium*, not the wages.

(4) It offered a real inducement to the workman to suggest improvements in his machine or tools. Under the piece-work system, so long as the machine was kept up to a certain standard condition of fitness, the man said nothing, as any improvement he was aware would probably result in cutting his rate. Under the premium system an improvement suggested by the man benefits him and the employer also, as (within reason) no rate cutting is found necessary.

(5) The system in its application gives accurate data for time-keeping and cost-keeping purposes. It acts as a double check on the time-keeping, and it associates on one form the article, the operation, and the time cost.

Many different applications of this system are in existence, most of which are excellent; but in considering their application the character of work being done under the system largely influences the correct choice. In the authors' works there is a large amount of repetition work and also a large amount of special work, but in no case are the operations carried out under a premium [contract of longer duration than about fifty hours. They therefore adopted the system of paying a premium of 50 per cent. on the time saved.

The following Table shows the result to the workman of the application of the system :—

Part.	Operation.	Time in hours.			Rate of Wages per hour.	Workman's Earnings.
		Allowed.	Taken.	Saved.		
10-inch Cast Iron Pump.	Boring out.	40	24	16	8*d.*	24 hours at 8*d.* + $\frac{16}{2}$ at 8*d.* = 21*s.* 4*d.*

It will thus be seen that the workman has earned a premium of one-third of his wages on this contract.

The cards used for contracts are shown on Figs. 1 and 2 (pages 900 and 901); Fig. 1 is the contract note, which is self-explanatory, and Fig. 2 the time card. This latter card is used when no time allowance has been fixed for the operation in question, and the larger part of the superintendent's duties are in watching the execution of work done under these cards, to enable a suitable rate to be fixed for use when the operation recurs. The men obtain their cards from the premium office, situated in convenient parts of the works; the time for commencing the operation being the time at which the card leaves the office, the finishing and commencing time of the cards coinciding; thus the preparation time for a job is considered and allowed for in the time allowance. In the case of special machines requiring a considerable time to adjust tools, etc., this allowance bears a ratio to the number of pieces to be done. On the completion of a contract the note is check-punched by the inspector, or the foreman of the department, who thus certifies the job to be done correctly and the full operation denoted on the card to have been carried out. To prevent any chance of scamping or bad work, a strict rule is enforced that if any part of work, however small, done under the contract, is not right, the man loses his whole premium under the contract. After consultation with the men, it has been agreed to pay the premium every four weeks, except before the two main holidays in July and December, when eight weeks are allowed to lapse before payment.

After more than three years' experience of the working of the system, the authors have found the following to be among the many advantages gained by its application:—

(1) It has resulted in a largely increased output from the machines for the same labour cost.

(2) An increase in their workmen's average wages of from 10 to 40 per cent.

(3) The practically compulsory maintenance of their machines in the highest state of efficiency.

(4) In a greatly increased interest of the men in their work, machines, and equipment, and a fair amount of co-operation in all the schemes for improving the factory.

(5) It has given the foremen a field for the choice of men they never had previously, resulting in the employment of only the best class of steady workmen.

(6) It has caused the foremen to be no longer merely taskmasters over the men, but to become more providers of work for them and inspectors of that work.

(II.) *The Friction Club.*—In every establishment shop problems of various kinds occur, the settlement of which affects different departments. It is not always convenient to get the different foremen together during the day to decide on these problems, and any discussions during working hours are apt to be hurried and conclusions drawn which maturer consideration may condemn. Data has frequently to be collected, and the points affecting different departments investigated thoroughly before a decision can be arrived at. There are also many suggestions of improvement made casually which may be recognised as good and worthy of adoption, but even the best shop manager is unable always to follow them up and see that they are carried to a conclusion. Further, after a suggested improvement is put into force it is frequently lost sight of, and its results become unascertainable.

FIG. 1.

No. ________

CONTRACT NOTE.

Job No. ____________________ Machine No. ________

Names, ____________________ No. ________

____________________ No. ________

No. of Pieces, ____________________

Article, ____________________

Operation, ____________________

____

Time Allowance, ____________________

Commenced, ____________________

Finished, ____________________

Time Taken, ____________________

Time Saved, ____________________

Work and Time Checked, ____________________

Remarks :— ____________________

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____

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Fig. 2.

No. ____

TIME CARD.

Job No. ____________ Machine No. ______

Names, ______________________ No. ________

______________________ No. ________

No. of Pieces, ______________________

Article, ______________________

Operation, ______________________

____

Commenced, ______________________

Finished, ______________________

Time Taken, ______________________

Work and Time Checked, ______________________

Remarks :— ______________________

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To secure a proper discussion on shop problems, and to provide machinery for the systematic carrying out of suggestions and reporting of results, it was decided to inaugurate at the works a club composed not only of foremen but of all the administrative heads of departments, drawing office, costing department, correspondence department, etc.

When the club was first proposed, its reception was not at all favourable; it was considered by the foremen that the discussions would breed dissension, that reflections would be made by one foreman on the work of another, and that generally it would give rise to internal friction. It was accordingly named the "Friction Club," on the principle that its mission was to be the elimination of friction. Its business was to discuss shop problems and decide on solutions, to institute improvements and provide the means of carrying them out to finality, to receive and adjudicate on complaints and suggestions. Its rules were made as elastic as possible. Its office-bearers consist of an executive committee of five, three chairmen, who preside in succession, and two joint secretaries. Meetings are held once a month in the evening; the proceedings are reported and copies are neostyled and given to each member for insertion in a spring binder with which he is provided. The business of each meeting is arranged by the executive, and deals with whatever shop questions are most pressing.

A club letter-box is provided in the shop into which members are requested to send notes on suggestions or subjects for discussion. This box is opened by the executive committee prior to the issue of the notice for the following meeting, and if any matter requiring discussion is received in the box, it is incorporated in the business for that meeting.

The club was started at first with some misgivings, but it has steadily improved and has taken its place as a most helpful factor in the establishment.

Among the matters dealt with by the club have been the following:—

(1) The establishment of a works library, containing books and current technical papers and magazines. The weekly technical

papers are available for members of the club one week after publication, the monthly magazines one fortnight. Books can be borrowed at certain hours from the library, and the private technical libraries of members of the firm are made available to members on application. (2) The workmen's suggestion scheme, as described later in the present Paper; (3) the admittance and course of apprentices in the works; (4) the lighting of the shops; (5) the arrangement of the firm's exhibit at the Glasgow International Exhibition; (6) the distribution of shop labourers; (7) shop hindrances—a report by each foreman on his department, indicating the hindrances interfering with the execution or output of the work of his department; (8) grindstones versus emery wheels; (9) wearing of overalls by the men, etc., etc.

The decisions of the club are, where necessary, submitted to the directors and receive their sanction before being put in operation, but as each of the three chairmen of the club is a director, this is usually a matter of form.

(III.) *The Workmen's Suggestion Scheme.*—Closely allied with the Friction Club is another efficiency factor which has recently been inaugurated in the works, namely, the Workmen's Suggestion Scheme. Encouraged by the success of the first few meetings of the Friction Club, it seemed a logical sequence that suggestions for improvement and reforms should be asked from the workmen themselves. Knowing generally the lines on which a similar scheme had been worked by the National Cash Register, of Dayton, Ohio, it was felt that, with modifications, some means could be attained by which the intelligence and observation of the workmen themselves might be encouraged and directed. Accordingly a scheme was promoted and discussed by the Friction Club, its purpose being to encourage the workmen to make suggestions for improvements in the shops, and on the work generally. The directors of the company agreed to allot a sum of £4 per month for the best suggestion, or suggestions, made by workmen by means of which an improvement could be effected on the machine tools, hand tools, jigs, fixtures, work methods, organisation, cleanliness, order, or other matters affecting the shops. All suggestions are signed with the workman's name and shop number, also a note stating whether the suggestion is original or taken from a technical journal or other source. The written suggestions are placed by the author in a box provided in the gate-house. This is opened daily by the club secretary, and the suggestions received are stamped with a date stamp when taken out, and are considered in order of priority. The judgment and discussion on the suggestions is conducted at the Friction Club, and also the allocation of the awards, the amount being given according to their decision in one or more sums according to the merits of the suggestions.

In deciding upon the awards, those suggestions which are considered of little merit are first eliminated, until gradually the best are left, and if any difference of opinion exists as to the comparative merits, they are voted upon. The names of the suggesters are not given to the meeting, but are known only to the executive committee. The successful suggestions each month are posted on a notice board provided for the purpose, but the names of the suggesters are not published.

If the merit of the suggestions is such that the awards do not absorb the entire £4 in any one month, the balance is carried forward and serves to augment the award for suggestions which may be considered of special merit.

During five months the total number of suggestions received amounted to 60; 3 the first month; 11, 8, 18, and 20 in the succeeding months; and of this total the number of suggestions adopted and carried out amounts to about 20 per cent. of those received, and are grouped under headings as follows:—(1) Cleanliness and Order; (2) Improvements in Machines or Methods; (3) Shop Fittings; (4) Safety Devices; (5) General.

The discussion on these suggestions has been most educative, and has resulted in several most excellent shop devices. The scheme has also been well taken up by the apprentices, and has directed attention to the men who can be drawn upon for promotion to responsible posts.

(IV.) *The Technical Committee.*—It will be noted that the Workmen's Suggestion Scheme does not include in its scope suggestions for improvement on the designs of the firm's product. It was considered that this would be likely to involve complications, and give rise to difficulties. Accordingly the function of dealing with designs, etc., lies with a committee comprising the managing director, shop manager, chief draughtsman, and draughtsman on special design. This body is called the Technical Committee, and besides the above members it can call to its deliberations any foreman or other administrative head, whose advice is required. It deals with the revisal of the designs of the firm's product, the carrying out of experimental work, the tabulation of results, the systematic consideration of complaints and defects, and the criticism and development of new designs. Further it considers the complaints which have been received by the Correspondence Department, and the reports of the firm's engineers who have been deputed to examine and rectify them. Each month the complaints and reports of defects received by the Correspondence Department are collected and tabulated under distinctive heads, and these are considered in relation to the design of the product.

The Technical Committee suggests modifications or carries out experiments to obtain data, and reports upon the results. It deals with new designs from the point of efficiency, cost of production, and commercial advantage. In the authors' experience the systematic tabulation and analysis of complaints is a most valuable help towards the elimination of small defects. In the rush of a busy day, a single complaint may be received, and the temptation is great simply to blame the personal element for neglect or carelessness, and to minimise its importance. But when complaints of a like nature are classed together and tabulated over a period, they have the force, not of single spies, but of battalions.

(V.) *The Intelligence Department.* — In discussing business principles Sir J. Wolfe Barry has mentioned as a most vital one—"the necessity of keeping *au courant* with what is being done or contemplated by others in similar lines of business, and of being well in touch with all probable new developments, whether of applied science or of labour-saving expedients, not merely in this country but among our world-wide competitors." The Intelligence Department deals with the collection of information and data required by the various departments and members of the firm; the indexing, cataloguing, and filing of technical literature, catalogues, cuttings, etc. It secures a systematic perusal of contract advertisements in the technical papers, marks and records openings for the firm's products, and keeps a card index of parties interested or likely to be interested in them. The principals or heads of departments furnish notes of special subjects on which they desire information, and articles in current magazines or papers are marked for their perusal. When the subject is a general or voluminous one, such as "Water-Tube boilers," Romeike and Curtis can be requisitioned. The technical index of the "Engineering Magazine" is also utilised, and special articles are obtained by coupon when required. These cuttings are filed under Department or Subject Heads in cardboard cases for reference.

Suppose the firm is considering any problem, say foundry equipment, the Intelligence Department is requested to collect the articles dealing with this subject, the various yearly indexes of technical papers are gone over, and if need be a summary is prepared for the Technical Committee, or the individual member to whom the question has been remitted. This method saves the time of the more expensive staff, and is a means of readily obtaining concentrated information with a minimum expenditure of high paid labour.

The duties of this department are of course not continuous but intermittent, and are combined with other clerical duties. In the establishment here dealt with they are undertaken by ladies, whose natural genius for detail makes them specially suited for this class of work.

These brief notes on a few shop schemes are submitted as showing developments in dealing with the minutiæ of an engineering establishment, which may be followed up with advantage, and also with a view to eliciting the experience of others on similar lines.

The value of the schemes has been found to consist in providing a medium through which the intelligence and ability of the staff and men are directly ascertainable, and in providing the machinery by which ideas and suggestions are methodically dealt with, followed up, and exhausted, before adoption or rejection.

They have also had the effect of bringing the men and their employers into more direct personal relations, and of creating a certain *esprit de corps* in the shops, the value of which, although not tangible, is nevertheless of a real and gratifying nature.

Discussion on the foregoing three Papers.

The Chairman said that these three Papers dealt with matters which were of vital importance at the present time when competition was so keen, not only in this country, but between this country and other nations. The three Papers had three special sources of value. In the first place, they set forth very clearly the conditions which had to be met if the relations between employers and employed were to be improved. In the second place, they described very fully certain schemes which had been carried into practice for improving these relations; and, thirdly, they gave them the results in practice of the adoption of these schemes. He thought that the Congress was very deeply indebted to the authors of these Papers for having put before them the results of their experience. The Papers would be of great permanent value, and he hoped they would elicit a discussion which would be really worthy of them. Before commencing this discussion, he asked them to pass to all the authors a very hearty vote of thanks for their trouble. He was very glad to see that Mr. George Livesey, who has taken such a very keen interest in labour problems and had met with great success in dealing with them, was present, and he would ask him to open the discussion.

Mr. George Livesey said he was to some extent an entire stranger there, as his business, the manufacture of gas, differed from that of the mechanical engineer, who was in competition with all the world. Gas companies were not in competition at all, but there were certain general principles underlying labour questions which applied to all, and the fundamental principle on which he had acted in introducing the profit-sharing system at the gas works was that it must not only benefit the employers, but also be a permanent benefit to the employed. Unless systems for promoting good relations between employers and employed were mutually advantageous, they came to nought sooner or later. The admirable Papers which he had had the pleasure of reading and hearing dealt with the first part of the question in a most satisfactory manner. They induced a workman to take an interest in his employer, and to do his best to turn out work to the greatest advantage, but he did not see that they resulted in any permanent good to the workmen. It was a permanent good no doubt to make a man take an interest in his work. They also tended to make him more industrious, and they also gave him more money, but what did he do with the money? He worked harder and made more money, but was it not almost a certainty that the increase was spent to no purpose.

Mr. James Weir said it was certainly not so.

Mr. Livesey: Did it do permanent good? Mr. George Thompson of Huddersfield, who had studied this question more than most men, lately, in reply to the question as to what he thought of paying the profit-sharing bonus in cash, said that it did more harm than good. Instead of promoting, it was a discouragement of thrift in many cases. If a man was thriftless he would incur debts in anticipation of the bonus of £2 or £3. He quite concurred with Mr. George Thompson. If it was to be a permanent benefit to the worker, inducements must be offered and facilities given to him to save the money, and thus improve his position. His own experience was that if his company had not adopted that plan, the system would have been dead long ago. The men were given the option of leaving their bonus at interest, or might take it out at any time they pleased on a week's notice. He was somewhat astonished when some 45 per cent. of the men left their money in the hands of the company, but the larger proportion took it out year by year, and as a rule spent it in various ways. The system was then altered, making half the bonus payable in cash, the other half being invested in the ordinary stock of the company. The workmen now had about £110,000 in stock and over £30,000 on deposit at 3 per cent. interest in the company. Ninety per cent. of the men were induced to save their annual bonus as well as the half invested in stock. Success was due to the fact that their profit-sharing had thus been a benefit to both parties; and good as this premium system was he feared it stopped short at the point of permanent advantage to workmen. Mutual permanent advantage was necessary, and mutual confidence was also required. The first step was that the employers must give the workmen their confidence before they could expect confidence in return.

Mr. Wigham Richardson asked if, when Mr. Livesey's company issued shares to their employees, they were handed over to them at par?

Mr. Livesey replied that they were handed over at the market price.

Mr. Arthur Greenwood said he would add only a few words to this discussion, and that particularly in reference to the premium system described by Mr. Rowan. The system they had adopted at their Works in Leeds was practically the same as that described in the Paper; and he agreed with everything that had been said in its favour. They had not only got a very considerable increase in the output, but they were creating a very much better feeling between the workmen and their foremen. One point he would particularly emphasise, and that was that the adoption of the system had led, for the first time in his experience, to the workmen coming forward

(Mr. Arthur Greenwood.)

with suggestions for facilitating the increased output. He thought for that reason alone the system should commend itself to all of those engaged in the engineering trade. The workmen saw that this was not a grinding system like some piece-work systems might become, but was a *bôna fide* attempt to interest him directly in economic measures for increasing the output of the Works.

As to the remarks made by Mr. Livesey, whilst congratulating him upon the admirable results he had obtained, he was afraid it was not a system that could be adopted in many engineering shops in this country, where they had such a large moving population through fluctuations in trade. He thought men would object to leave their premiums invested in workshops where they had ceased to be employed. He might add that they had only adopted the premium system in one of their departments at present, but he thought it was most probable that they would carry it out in other departments, in preference to the ordinary piece-work system.

Mr. W. H. **Allen** said that one of the most important objects that every manufacturer should have in view was to encourage British workmen to do a little more. The Papers which they had heard read showed that the masters were now taking much more interest in providing good, light, and clean workshops for their men; and he felt sure that this would help largely to encourage their employees to do not only more work, but accurate work. The Paper which Messrs. Weir and Richmond had read showed what advancement had been made in the North, and those who have had the privilege of going through their works would endorse his opinion, when he said that their new works seemed to embody all that was desirable for the welfare and comfort of the working man.

In reference to their method of paying for suggestions made by the men in the improvement of workshop practice, his firm had tried that plan for some considerable time, with the result that the men fell off in their efforts, and had to be whipped up to the point frequently. He thought it was most difficult for a working man, who was expected to employ his mind and body nearly all day in working on a particular job, and who had little time for study at home, to compete with young college men in matters of improvement, as they had a much greater opportunity of thinking how to improve matters than the man who had to do the practical work; they had tried the prize system themselves with partial success only. He was not satisfied as to whether the premium system was any advantage over piece-work, and would like to ask Mr. Rowan whether he could tell him if, in the whole year, the men obtained better wages under this system than under the old piece-work arrangement.

Mr. **Alfred Saxon** said that the three Papers they had listened to were Papers that were very necessary at the present time, in connection with the competition with which they had to deal. As one of those who visited the works of Messrs. Weir yesterday, and who did so before reading this Paper, immediately he entered into their works he formed an opinion that it was a very well-managed shop, and that it was being worked on the best possible lines.

He found that nearly the whole of the machines, so far as one could judge by a casual look without any measurements or tests, were working well up to their capacity. He noticed one or two things that he hardly considered would quite pay; for instance, one heard about a man minding half-a-dozen machines, but in this particular works they had two men minding one machine, and that was repeated in the case of another machine alongside. He wondered, when the Paper was being read, and with the amount of criticism and suggestions by workmen, that the managing Committee had allowed this arrangement to continue. He was quite sure that they could obtain a machine which one man could handle, and so dispense with this surplus assistance. He was connected with a business where he was at a loss to see how the premium system could possibly be applied or even to a great extent the standardising of work.

However, he might say that since the application of one or two special machines he had found that even in works of a general engineering character, such as the works he was connected with, they have been able to do more standardising than was expected.

Mr. HANS RENOLD was much interested in the three Papers read by their Scotch friends. Dealing as they did with the social administration rather than with the technical management of engineering works, they touched one of the weakest points in our competition with foreign engineers.

In his own works they had at one time the piece-work system, but for several reasons had found it wanting, and had since for years paid the men by time. This again could not be considered satisfactory, because weekly wages could not be regulated to give due extra pay to those who produced extra quantities and good work. The premium system, which they had worked with a small portion of their men for some little while, seemed more to meet the case. It allowed the ordinary man to earn ordinary wages, and a good man to get extra pay. At the same time it benefited the master to the same extent as it did each particular man. Though a step in the right direction, the premium system was not yet a complete solution of the labour problem, and a further step in the direction indicated by Mr. Livesey would sooner or later become necessary. Under the premium system a price once fixed must on no account be disturbed, except it be that the tool or method of working be radically changed. For this reason the quantity which could be made in an hour or week must be most carefully considered, and required of the management much more conscientious investigation than was usually given when piece-work prices were fixed, which, as was well known, were often and very lightheartedly altered as soon as the workman was making his wages with an addition of about 30 per cent. The rock then upon which the premium system rested was the confidence it gave to the workman to make as much as he could, for he knew there was no inducement to the master to alter his rates, being equally the gainer along with his workman of the extra work he did.

He was glad to hear Mr. Allen say that he had succeeded in getting some "caps and gowns" into his works, and that he was getting from them a great deal of new and valuable suggestions; but he thought the premium system would bring to the front our more bright and clever workmen, and from them we should also get valuable suggestions. His experience of several journeys to the

United States had led him to feel that across the Atlantic the master was getting more help from his workmen than they did here, and it was because the workmen there received more inducement to come forward in the shape of extra pay for extra work; in short, he had more chances given him to show his ability and to rise than was the case in English workshops.

Mr. T. Hurry Riches said that these Papers had raised a problem which he had looked at with considerable interest for some time. He was not sure that there was quite as much difference between the system of piece-work and this system of premium, and was not satisfied that there was the same inducement for a man to work; he could not see that it was going to afford relief from inspection of that work. In his own district he was acquainted with several cases where workmen participated in profits, and so long as there were any to participate in, the workmen were satisfied; but as soon as a depression of trade arose and the profits diminished, the workmen at once wanted to know the why and wherefore, and did not appear to be at all desirous of reducing their rate of remuneration, although the manufacturers were obliged to take much lower prices for their goods, and consequently were in some instances even losing money. He thought this was very generally the case in the South Wales coal trade, for so long as the market rose and the sliding scale kept going up, the colliers and their representatives appeared to be satisfied; but as soon as the pendulum began to swing the other way, then they heard of grumbling all round and of threatened strikes, which was very discouraging to those who advocated making the workman participate in profits.

He was interested to hear Mr. Livesey, but it seemed to him that Mr. Livesey was placed in a rather unique position. He supplied a commodity which nearly every one was bound to buy, and it was purely a question of what it cost him to manufacture, as he had the right to raise his rates or lower them in proportion to his cost of production, and thereby to ensure fairly a regular profit to his company and workmen. He was also pleased to hear that Mr. Livesey had endeavoured to induce the workmen to make proper use of what

(Mr. T. Hurry Riches.)

might be termed their extra profits in prosperous times. He knew one or two instances where provident societies and savings banks had been introduced for the good of the workmen, but only a comparatively small proportion of the men had in such cases really availed themselves of the advantages so offered.

His experience had been that workmen as a whole were not very provident, and that when in prosperous times they were paid good wages they also spent it very freely, and when times were bad they had a great deal of difficulty in bringing their expenditure back to the limit of their income, and that frequently brought trouble upon them.

Mr. Allen had dealt with the picturesque aspect of encouraging his workmen. That might be one very good way of making life as happy as possible for those about them, but he was not sure that the "picturesque" had much to do with the question. He quite agreed with him that a good workshop was a necessity; it was as much in the interests of the employer as in the interests of the workmen. Light from the sun was very much better than having the gas burning all day. He was struck with one or two remarks made, he thought, by Mr. Rowan, who referred to the increased work done by the machines, and understood him at the same time to say they did more work, but they, in fact, raised the work into a stronger machine. He was very cordially with him there. So far as his experience went he had been seeking to do his work on heavier machines to get bigger cuts and greater speeds. As to the question of consultative meetings with workmen, he had often received good suggestions from the better-class workmen, and found them often ready to suggest improvements in method and in machines.

Reverting for a moment to the question of piece-work as compared with the premium system, it seemed to him that this question of premium was tied up with it, in the way that first of all a rate was fixed, and the workmen were allowed to derive 50 per cent. of the profit, which was made by reducing the time necessary to do that work. He failed to see the difference between fixing the piece price to give the man the whole of what he earned, and fixing a fictitious price to enable half of the profit to be taken by the employer and the other half by the workman. It appeared to him that the workman was very likely to want the whole.

Mr. WICKSTEED said it was because he was helped with better appliances.

Mr. RICHES, continuing, said it was to the interest of the employer to provide the best appliances to reduce the piece price, and it ought not to be necessary to fix fictitious prices. It was the duty of the shop manager, the foreman, and the employer to see that the best appliances were provided, so as to get the maximum work, if the money was available for their purchase, and therefore the question of appliances must be dependent to a great degree upon the extent of capital.

Mr. ROWAN in reply, said that they had had many proposals from the men to improve the output of their machines; it was not the exception but rather the rule. Most of their men knew that it was to their interest to increase their output; still some did not increase their output as they might do, being suspicious of their time being reduced; these men would continue doing so till the end of their days. The firm had men, since this system was introduced three and a half years ago, who were repeating the same work, and whose rates had never been cut. Some of these men were earning on many jobs 50 per cent. on their wages, and they were encouraged and helped to the utmost.

The question of inspection had been raised by one or two speakers. He might say that, in his opinion, no matter how a man was working, inspection was required; but their experience was that they were getting infinitely better work out of their machines and from the men under the Premium System than before it was adopted. This was of course due to measures which ran concurrently with the introduction of a premium system, such as the introduction of gauges, jigs, etc., and the abolition of the use of foot-rules and callipers. Mr. Livesey commenced his remarks by saying that he was ignorant of the class of men with whom they were dealing. He

(Mr. Rowan.)

himself thought that, in view of his following remarks, it was well that he started with this statement, because a good many of his remarks were quite uncalled for. Mr. Livesey went on to state that the money earned by their workmen through the introduction of the Premium System was almost to a certainty spent to no purpose, and that a profit-sharing scheme must not only benefit the employers, but must also be a permanent benefit to the employed. Theirs was such. The men who were employed by them and working on the Premium System—and he believed the same remark applied to Messrs. Weir's men—were as respectable a body of men as there were at the Meeting. They were as well able to take care of money and as well able to benefit by it as the gentlemen sitting there. They had put them in the way of earning more money: and his firm was also deriving the benefit by the introduction of this Premium System. The men might invest their money as they chose; and if one could judge of the respectability of men by the regularity of the hours they kept and by their general conduct, he would say that the men had derived great benefit, due to their increased earnings. He could not understand Mr. Livesey speaking in the way he had done, unless his experience had been of a totally different character to theirs.

Mr. THOMSON, in reply, said that there had been no remarks made to which it fell within his particular province to reply, except those of Mr. Riches. They got their work done in less time by doing it with heavier machines; and a study of Tables 1 and 2 (pages 886 and 889) would show this.

Mr. J. R. RICHMOND, in reply, said, while appreciating Mr. Livesey's remarks, he would say their experience was, that the more remote a workman's reward became, the less result was obtained. When a workman received his bonus in tangible form every week, the immediate result of the effort appealed to him directly. As to the application of his earnings, he could scarcely agree with Mr. Livesey, as, by the adoption of a premium system, the most intelligent and best class of workmen were attracted, and these were capable, square-headed fellows, who knew how to apply their money judiciously.

Mr. Allen considered that improvement schemes were apt to suffer after a time from lack of interest, and this was undoubtedly the case, unless the principals in a business gave personal attention to such schemes. It was absolutely essential for the success of such developments that they should, by their interest and example, imbue the men with a spirit of enthusiasm.

As to the quality of the suggestions elicited by the suggestion scheme, they received a number which could not be called brilliant, but, on the other hand, they received some exceedingly good suggestions, and they found the men who made the suggestions coming up with fresh ideas month after month. The scheme was thus, in a way, selective of the men with the brains, and these were the men they promoted to responsible positions when such were vacant. The men were the raw material from which foremen were made, and foremen, not unfrequently, were the material from which the most successful captains of industry were made. While, therefore, he recognised the value of the "cap and gown" men for certain classes of work, at the same time, he was strongly averse to undervaluing the capacity and intelligence of our workmen when opportunities were given them.

The Chairman thought they had every reason to be satisfied with the discussion on the three Papers, but the subjects with which they dealt were not exhausted; and if any gentleman had any contribution to make in respect of these matters, the Secretary would be glad to receive communications in writing for incorporation in the discussion when printed, and proofs of such contributions would be sent to the authors of the Papers so that they might receive attention at their hands.

Communication.

Mr. Philip Bright wrote that he had found the practice of inviting suggestions from workmen very successful, and almost half the suggestions made in this manner in the works with which he was connected had been adopted with advantage. It was easy in this way to find the more intelligent men, and they could be promoted as opportunities presented themselves. He had no doubt that the premium system was better than piece-work, both for employers and employed. When men were working piece-work, they rarely welcomed the introduction of new machines or methods of working, as they were likely to upset the piece-work rates of the shop. In the London district brass-finishers did not earn more than one shilling per hour, though exceptionally quick men could earn, on certain work, probably eighteenpence per hour; this restriction of output was caused by fear that the rates would be cut and the slow men thus prevented from earning good wages. The premium system would, if it were clearly understood that the time limit was fixed once for all, induce men to do their best, and there would consequently be an increased output and higher wages for them. It was far easier to introduce the premium system in a day-work shop than in a piece-work one. He proposed it in his own works where nearly all the men were on piece-work, but they declined to work under it; but lately he had had an intimation that certain men would like to try it. He thought the plan of having a fixed hourly or weekly rate for men on day work was bad; it gave the quick and ambitious men no chance of distinguishing themselves; if they knew that they had a chance of getting a higher rate it was an incentive to work more quickly. Some men were worth twice as much as others, and he thought employers rarely had the courage to recognise this and to reward them accordingly.

THE ADOPTION OF THE METRIC SYSTEM IN OUR WORKSHOPS.

By Mr. ARTHUR GREENWOOD, *Member*, of Leeds.

With the object of obtaining an expression of opinion of those connected with the mechanical engineering trades now assembled in Congress at Glasgow, the author has ventured to express his views as to whether the time has not now arrived when some steps should be taken towards the adoption in our workshops, in a more or less complete form, of the metrical system of weights and measurements now generally in use on the Continent of Europe.

At the risk of possible opposition, he is prepared to avow that. after a not inconsiderable experience in international trade, in which he has been personally engaged in pushing the sale of British machinery in foreign countries, in opposition to machinery made abroad, he would gladly see the adoption by this country of the metric system in its entirety—money, weights, and measurements, as established in France in 1799. Being moreover a Free-Trader in the widest sense of the word, he would not hesitate to adopt from the foreigner anything that is better than can be found at home. Possibly there may be some prejudice in favour of the French system arising from the fact of his having been educated in that country—now unfortunately more than forty years ago. The facility of learning the metric system as taught in French colleges made a strong impression upon him, as compared with his earlier experience at school in England, in endeavouring to master the British weights and measures. The former is learnt with very little trouble, and is so simple and self-evident, that it remains lastingly impressed upon one's mind, whilst the latter is so complex and irrational that, although one may suppose it to be possible of acquisition, unfortunately it does not remain impressed on one's mind, seeing how often in after life one has to refer to books, when it is necessary to make a calculation outside the run of every-day work.

It would possibly be wiser to eliminate from this discussion the question of money and monetary standards, as being a subject of which we mechanics know little, leaving it to be settled by those who make more of it, and consequently may be assumed to know more about it; although it must be admitted that a system, which enables one to use the current coins of the realm as standards of weights and measurements, offers advantages that the humble mechanic would at times appreciate.

In the first place it will be expedient to consider what advantage would accrue to the mechanical engineering trade of this country by the adoption of the metric system. If this country could afford, or if it were possible, to build a wall round its Empire, and the engineers were to devote themselves simply to the manufacture of engines and machinery required in its own workshops and factories, neither selling nor desiring to sell anything outside the Empire, there would be no reason why they should not continue to muddle on with feet, inches, sixteenths, thirty-seconds, and hundredweights, quarters, pounds, &c., for all time, wasting the energies of the student in endeavouring to comprehend our harlequin system, or rather collection, of standard weights and measures, instead of giving them instruction that would be of permanent use to them; and employing hundreds of unproductive clerks in our offices when tens would suffice. It would be our own affair, and our own insular privilege to continue, if we thought fit, a system which has been condemned by most nations of the earth, and who might probably continue to laugh at our peculiarities and prejudices. But it may be assumed that the British mechanical engineer cannot afford, and has no desire to be content with any such position. He is determined to continue the efforts he has up to now successfully made, in spite of what has been lately said and written as to his decadence, to push his manufactures in every market in the world. He has to meet competitors from America, Germany, and France in the countries of Europe and elsewhere where the metric system is universal. Germany has followed the lead of the Latin countries, and has abolished her many standards of feet, and Austria has done the same. Russia continued to honour us for years by using our standards, and still does so to some extent, but in Russia before very long the metric system will be as general as it is in Germany, thanks very largely to German propaganda in that country. If the British mechanical engineer is to hold his own in these markets, it is imperative that he should offer goods to conform to their usages in dimensions and weights. The author would appeal to those of his engineering colleagues who have doubtless found themselves in the same desperate position he has found himself, provided with a drawing of an elaborate machine carefully scaled to an inch or an inch-and-a-half to a foot, and with probably a very imperfect knowledge of the language of the country with which he desires to transact business, and endeavouring to answer the numerous questions of an inquisitive and intellectual foreigner who wants to know the dimensions in millimètres and weight in kilogrammes of particular parts of the machine. Under such circumstances the wonder is that orders could be obtained at all, and considering the disadvantage under which he has shown his wares, success in obtaining orders can only be considered a tribute to excellence of design. True, experience has taught many engaged in Continental trade to have plans drawn to tenth scale, thus somewhat mitigating the difficulty here alluded to, but no one can possibly maintain that the seller's position would not have been wonderfully improved, and his own and his prospective purchaser's temper less sorely tried, had he been provided with drawings in metric scale, and with weights indicated in kilogrammes instead of tons and hundredweights.

From consular reports they learn from time to time of England losing orders for hardware and textile goods, owing to manufacturers not troubling to make them in accordance with the standards of other countries, and they do not hesitate to condemn their want of enterprise and old-fashioned practice, and point out to them that it is no wonder that Germans, for instance, who, above all nations, endeavour to offer goods to meet the wants of other countries, are obtaining trade that heretofore came to this country. The author could quote numerous cases of orders from France, Germany, Russia, Japan, and South America, that might have come to England, indeed would have come, but for the reason that the purchasers preferred buying machinery which admittedly was not so good or so suited to their requirements, but which conformed to their metric system. Is it not therefore beyond doubt desirable, from the point of view of international trade, that engineers should adopt the system of their customers.

It will probably be advanced that America, who is likely to be Britain's greatest competitor in many of these markets, still continues the foot and ton standard. This is certainly the case, but she has in addition universally adopted the decimal division of inches and tons, and, judging from what appears in American engineering journals, manufacturers there are being urged to adopt the metric system, and that if, as is undoubtedly the case, she really intends to grapple with the trade of Continental Europe, it may safely be predicted that before long she will avail herself of the additional advantages to be gained by offering goods made in accordance with the standards of her desired customers.

Assuming, then, that for the purpose of foreign trade, the metric system would be of use to mechanical engineers, it becomes necessary to determine the difficulties standing in the way of its adoption, and whether these are due to the system itself. This is certainly not the case, as anyone who has once tested it must admit it is simplicity itself. American and English critics have advanced the plea that the fault of the system is the unit; the millimètre is too minute, the centimètre is not large enough, and the mètre is too large, and that there is practically no convenient substitute for a foot or for an inch. With due respect to the gentlemen who have expressed these objections, they might be placed in the same category as a distinguished member of the House of Commons to whom the author was endeavouring some years ago to explain the simplicity of the metric system, and how calculation and book-keeping generally would be simplified by its adoption as compared with the present system of hundredweights, quarters, pounds; and pounds, shillings and pence. His reply was: "What does it matter, you can have your ready-reckoner for a few pence, that does all that for you." These objections, to the author's mind, are not real, and may be put down to prejudice and that conservative feeling so strong in the Anglo-Saxon breast.

The one serious objection is the cost and trouble of making the change, but this is a difficulty that can be overcome if time is taken to bring about the change. Our legislators so long ago as 1864 made its use permissible, and it is for the leaders in the various trades most concerned to take the next step, and certainly to no trade is it so important as to that of the mechanical engineer; and it is for him to attempt its introduction in, at any rate, one of the branches of his business that is most connected with foreign trade. It is simply a question of rules, callipers, standards, drills, and reamers, which, after all, is not very serious. The equivalents can be made from existing standard leading screws in lathes by means of change-wheels.

The mention of screws at once calls attention to the most serious part of the suggested change; but that difficulty can be easily met. It would be worse than folly to attempt at present to change the standard pitch and form of screw threads so admirably standardized by Whitworth, and so widely adopted, until a better standard is agreed upon to put in its place.

Much as one would wish to see the metric system adopted in its entirety, it would be well at present not to advocate any departure from the Whitworth standard thread. The two systems can and do work admirably together side by side in many shops in France, Germany, Russia, and Sweden. France has attempted to establish a metric system of screws, and has not been successful, for in the majority of her shops the Whitworth standard remains. She, like America, attempted to alter the form of thread, and ignored the rounded top and bottom, so admirably established by Whitworth.

The screw question should be left to be settled, as it must be ere long, by the establishment of an international standard, the result of an international congress, for which the common sense of engineers—foreign and British—must before long see the necessity. Meanwhile, things can go on as they are, and probably Whitworth's will survive as the fittest, until some congress establishes a system which should, of course, be metric in pitch, but, let us hope, Whitworth in form of thread.

Much has been said lately about the metric system being made compulsory. Parliament has made it permissible, private initiative should demonstrate that it is practical and advantageous, and should then call upon Parliament to make it compulsory, but, above all, give time, as with the French. It would be a mistake to say two years—a period that has been advocated. Twenty years would be nearer the period in which to make it compulsory, but doubtless it would be generally adopted long before that time for that best of all reasons, namely self-interest.

It was suggested at the commencenent of this Paper to leave the monetary standard alone, but a plea might be advanced that whatever unit is ultimately adopted, it may be decimally divided, as has been done by practically all nations.

The object of this Paper is to put forward a claim for the adoption of the metric system for weights and measures, the latter term applying also to lineal measures and surface, and to measures of capacity. Special standards for special articles in particular districts should be abolished, and the sale of precious substances and drugs at the rate of 5760 grains to the pound, and steel, beef and sugar at 7000 grains, be ceased. Civil engineers should give up expressing in yards, chains, and furlongs, and adopt a mètre standard, and let surveyors abandon their rods, poles, perches, roods and acres, and express themselves in ares, and the litre be substituted for gills, pints, quarts, and gallons. Solid cubic measures should be known as stères, and let mechanical engineers adopt the mètre and the gramme, instead of the present confusion of quarter-inches and sixteenths, and pounds and their perplexing multiples.

At the same time these measures should be adopted with their Anglicised French names, and thus avoid the confusion that has been made in Germany by attempting to hide the French origin; it would be a graceful act to perpetuate the French origin of the mètre standard. Nothing could be simpler than their adoption of Greek derivatives of Deca, Hecto, Kilo and Myria, for the multiple of units, and the Latin ones of Deci, Centi, and Milli, for the division of the units.

The scientific world have adopted the metric system, even enlarging upon it for chemical and other purposes of research, and having to deal with smaller units they have by international conference adopted the micron as the one-millionth part of the mètre. Let them follow their scientific leaders in this respect, and also in their adoption of the system of Celsius for the standards of heat and cold.

In conclusion, the author would like to add briefly his own experience of the metric system. For the past twenty-five years, the metric calliper-gauge has been often quite as familiar in the tool room at the Albion Works as the inch one, and very little difficulty has been met with from the men, who soon learn to work one system as well as the other. In the engineering works in Russia, in which he is interested, both metric and English standards are used, and little difficulty is experienced in their joint use. In Russia the standard is in a transition stage, and everything would point to the prevalence of the metric system in a short time. At the new workshops just completed at the author's works in Leeds for the manufacture of the De Laval steam turbine, the metric standard has been adopted in combination with the Whitworth standard of thread.

Discussion.

The Chairman said the Paper was one of very great value. It dealt with a question which he might describe as a somewhat unpopular necessity, he meant the necessity of manufacturers realising that for certain markets they must use the metric system. Mr. Greenwood had dealt with the matter in a very practical way, and had shown, he thought, that if they were to take time enough, the change could be made without any very undue loss to the firms who adopted it.

Mr. W. H. Allen said that the metric system had not been adopted at his works, but a considerable change for the better had been made by adopting the division of an inch into 1000 parts. This had now been at work there for the past five years with excellent results, although there was some slight difficulty and prejudice at first; it certainly did not require more than three months for the whole of the men to thoroughly understand what was meant by a thousandth of an inch. Bearing in mind that the object in reading this Paper was simply to discuss the metric system in conjunction with engineering work and allied industries, they need not go into the difficulties which would follow, if they attempted a similar introduction for agricultural purposes; in England the various descriptions in weight, measure, and names employed in various counties would present many difficulties.

He had frequently tested the efficiency of the decimal system in his works, and had noted from time to time the ease with which all classes of individuals, even down to the labourers, could speak of a measurement in figures instead of words. They must thank the author for his Paper as being one which had a very wide area, and which brought before them the fact that the metric system would be employed throughout every country in Europe at some future time.

Mr. Hans Renold said it was rather too late in the day to advance any plea on behalf of the decimal system, so admirably worked out by the French and adopted in their measure and weight system. Any one who had given this subject a thought must see that it has many advantages over the English want of a system. In 1881 and 1882 he adopted the mètre measure in his chain manufacture, but evidently before the times, for he had to give it up again. Since then he had been working in decimals of inches, and had found no difficulty in getting the workmen to understand them after a little instruction. Unfortunately in most Board schools decimals were not yet taught at the present day. He could not conceive how fine machinery or accurate work could be done without measuring in thousandths of an inch. A yard if decimally divided might be as good as a mètre, but in making a change it would be the height of folly not to fall in with what French, German, Swiss, and almost all commercial nations have adopted. As a nation, do what they would, they must export and import, and therefore might as well weigh and measure in the same system as those from whom they bought, and to whom they sold.

The question before this meeting, he took it, was:—"How were they going to get this metric system adopted in their engineering works?" To his mind, no help could be expected from the Government, and the only way to get this boon was to help themselves. If some fifty, sixty or a hundred of them there assembled would stand together and vow that each of them would, within a year, take steps to make a beginning in their own works and extend it, within three to four years it would be an accomplished fact.

Colonel P. E. Huber, Zürich, said he would only express his opinion as to the application of the metric system to the threads of screws and nuts in general, as treated in the International Congress held at Zürich in October 1898, where the engineering societies of Germany, France, Italy, Holland, Russia, and Switzerland were represented. This congress accepted unanimously, on the ground of elaborate investigation of the committee, a new thread-system, named the International System (I.S.), based on metric measurements, and

(Colonel P. E. Huber.)

they recommended its adoption by those who wished to work on metric measurements. The promoters of that congress did not intend to do away with the two existing systems based on the English measurements—the well-known "Sellers" system, generally used in America, and the "Whitworth" system, used in England and adopted by a great number of firms on the Continent, but found it absolutely necessary that the first step to be done in the way of having a really universal thread system was to enforce a unification of the different systems of metric measurements, as metric measurement was already now used very extensively in different countries and enforced by all the continental railway companies, as well as by a large number of governments. The products of mechanical engineering were spread over the whole world, and there should be no difficulty anywhere in replacing bolts and nuts for repairing purposes. If there was only one system, based on English measurement, the question could have been raised to adopt this system, but there were two in existence, and as the metric system would sooner or later be adopted by the great majority of engineers, the resolution of the said congress would be very useful, as it had proved to be a real advance as compared with the Whitworth system. The following firms, well known for their excellent work in tools, were producing the dies and templates as well as all the tools necessary for the working of the I.S. system, which was already now very largely adopted on the Continent:—Messrs. Barriquand and Marre, Paris; J. G. Reinecker, Chemitz; Loewe and Company, Berlin; and Reishauer and Company, Zürich. He concluded with the hope that the metric system would be adopted more and more, not by enforcing it but by its own merits.

Professor Archibald Barr said he was delighted that Mr. Greenwood had taken up this matter so heartily, as he seemed to have done. He believed that there was no reasonable compromise between their present want of system and the adoption of the metric decimal system. If one might with all reverence say so, it might be unfortunate that Nature did not endow them with twelve fingers, because then the whole system of digits would have been founded on the duodecimal system, but as it happened that nature had given five fingers on each hand, the decimal system of numeration had come naturally to be adopted, and there was no going back on that now. It was usually lost sight of that the decimal system was first propagated so fully upon the Continent through the advocacy of James Watt.* They had not the duodecimal system in this country. The yard was divided into three, and the inch into eight, and the quarter into twenty-eight. If they had a consistent system there would be something to be said for it, but he thought when a new system was adopted it must be the metric system, and be made universal for the reasons that the other speakers had already mentioned, and which were clearly set forth in Watt's letter. He would only disagree with the author on one point; he thought twenty years too long a time to allow for the introduction of the system. The use of the decimal division of the inch would be a step towards the ultimate adoption of the mètre, as it would familiarise workmen with working in decimals. He thought the Institution of Mechanical Engineers should take a strong stand in the matter.

The Chairman enquired whether the speaker used the metric system in his training in the University.

Professor Barr replied that it was not at present in use in the Engineering Department, but all the students were quite familiar with it, because it was always used in the Physical Department. The students were accustomed to both systems, and found no difficulty in working the metric system.

The Chairman said that would be a great aid to the adoption of the metric system as those students got into practical work.

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* *See* Letter from James Watt to Mr. Kirwan, dated 14 November 1783, in Muirhead's Life of Watt, vol. ii, page 179.

Professor BARR said their machines, screws, &c., were not made upon the metric system, and that made it difficult to use the system in much of their work.

Professor SCHRÖTER was afraid that this subject was not just in his line of working. As they were aware, he was a professor and was very happy to say that, in Germany, they had only to do with one system; and if he imagined the state of mind of the students of Professor Barr who have to do with two standards, he did not envy them. It was his opinion, and he thought it was shared by almost all the gentlemen present, that it would be a benefit to the whole profession if only one system of measurement was adopted whatever it might be, and that this one system would be the metric system was doubtless. He had no need to dwell upon the point. He wanted in concluding to profit by the occasion and to thank this Congress and the Institution of the Mechanical Engineers for the good reception they had given to their foreign guests. He could only say that they were very much satisfied with the proceedings of the Congress and with the meetings they had had occasion to take part in, and they would take home with them the best recollections of this Congress.

Mr. F. HOWARD LIVENS said the merits of the metric system were not under discussion, but on the question of its adoption, the opinions of those making commercial work in this country were required, because they would be fully alive to the real difficulties; when a series of new patterns, templates, and jigs were to be made, it did not appear to be difficult to adopt metric measurements, but where there existed a large stock of patterns, &c., in continual use, from which machines have been supplied for years past, it was a very serious matter to make the change, as duplicates must be supplied as before. Engineers in this country using the metric system, such as Messrs. Willans and Robinson and the author, had apparently adopted it only for new specialties, and as might be gathered from Mr. Renold's remarks there was considerable difficulty in the way. The speaker, although greatly in favour of the change, was of opinion it would require considerable effort on the part of the Institution of Mechanical Engineers. A committee would have to investigate and press the subject, and considerable time must be allowed, so that manufacturers could take it up step by step when getting out improved designs.

The Chairman said there was so much business to get through that morning, that he was afraid he must now close this discussion. The subject was a very important one, and he hoped that all who were interested in it would send written communications to the Secretary for inclusion in the Report. It was one to which the whole morning ought to be devoted. Professor Schröter had expressed very kindly the appreciation of the foreign delegates of their reception here. He was sure that any pleasure they had derived from coming to this Congress was more than equalled by their pleasure in seeing them here. He hoped this was only one of a number of occasions on which they would take part in such proceedings. He would now request Mr. Greenwood to reply to the discussion, but before doing so would ask them to give him a hearty vote of thanks for his Paper.

Mr. Arthur Greenwood said the reception which the subject had received did not leave him very much to say. He was in hopes that they might have had a more unfriendly discussion, and thus brought the discussion to a more acute state. There was a general consensus of opinion in favour of the metric system, and to use Dr. Barr's simile it was a pity they had not appreciated the purpose of their ten fingers sooner. His object in writing the Paper was principally from an international trade point of view, because that was, he took it, one of the main things that they as engineers had to consider. They did not want to be shut out from the trade of the rest of the world. If they waited for Government interference, they would have to wait a long time. Government never did anything until forced, and if they as engineers saw the economical and commercial value of the change they must make it themselves, and then put pressure on the Government to make it compulsory. Exception had been taken to

(Mr. Arthur Greenwood.)

the term of twenty years in which to make the change compulsory. That was merely a suggestion, because he thought that some of the Chambers of Commerce had rather injured the question by wishing to force the change too rapidly; and to make the change compulsory in two years would be very foolish indeed. He would particularly allude to Mr. Livens' remark that it would be a very serious matter for those who had standardised manufactures to change suddenly to the metric system. All good standard works have to be issued in new editions from time to time, and all he would suggest was that when a new edition came, let it be made in the metric system. The screw question was also a serious one. What had been adopted in Germany and in France, as described by Colonel Huber, appeared to be a step in the right direction, but he thought the question was such a great one that it could only be definitely and satisfactorily settled at a later period by international congress. He looked upon it as a matter of the greatest importance that they should bring this subject forward constantly at all their congresses, so that it might be impressed upon the public generally. With reference to Mr. Allen's question as to his personal experience, they had adopted and had used the decimal system in inches for a long time past in most of their departments. It was found impossible to work with the old system. They had adopted the metric system, for purely economic reasons, in their new works in Leeds in connection with the De Laval steam turbine, as that was an international machine, being made also in Sweden and France, so as to have only one set of standards, and in due time he looked to adopting it over the whole of their establishment.

Note.—For information about the working of the Metric System in workshops of the United States, see Paper by Mr. Coleman Sellers, American Society of Mechanical Engineers, 1880, page 7.—[Secretary, I. Mech. E.]

THE 100-TON UNIVERSAL TESTING MACHINE, WITH VARIABLE ACCUMULATOR, AT THE JAMES WATT LABORATORIES, GLASGOW UNIVERSITY.

By Mr. J. HARTLEY WICKSTEED, of Leeds.
Vice-Chairman of the Congress (Section III.)
and
Vice-President of the Institution.

The whole arrangement of the testing machine is shown on Plate 162. The straining frame is worked by a hydraulic ram supplied with water from an accumulator. When the valve between the hydraulic cylinder and the accumulator is open full-bore, a test can be made at the rate of 100 inches straining per minute, but the valve can be regulated so as to reduce the speed to a tenth of an inch per minute. The speed is under easy control through a wide range, and it can be altered at pleasure during the progress of a test. Thus the speed may be slow until the elastic limit is reached, and increased during the plastic stage. This facility for varying the speed, together with the absence of all vibration, makes a hydraulic straining gear worked from an accumulator preferable to any other system. It is due to Dr. Kennedy to state that he advocated this system in 1885, and stated in a Paper read before the Institution of Civil Engineers,* that "probably the maximum in steadiness as well as of convenience in working will be found in some such system."

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* Proceedings Institution of Civil Engineers, vol. lxxxviii, page 21.

In fluid connection with the straining cylinder there is an autographic recorder, which draws a curve produced in one direction by the pressure in the straining cylinder, and in the other direction by the strain of the specimen. Friction in the ram of the recorder is overcome by causing it to revolve, and the indications of the latter are calibrated from the steelyard of the testing machine, so that the friction in the main straining-ram is accounted for. If the hydraulic valve were opened full bore, it would not be possible to adjust the poise-weight so as to keep the steelyard in equilibrium; but when once the hydrographic recorder has been calibrated, the poise-weight may be taken to the extreme end of the steelyard, and a full test can be made without rocking the steelyard, the result being obtained from the autograph.

In Fig. 1, Plate 162, the testing machine is shown in a somewhat diagrammatic form, so as to clearly illustrate the principle of its construction. The machine consists essentially of a straining system embraced by a weighing system. The straining system consists of the hydraulic cylinder, ram, and notched frame which slide out, carrying the straining crossheads A and F. The weighing system consists of two long parallel rods with the three crossheads or weighbridges B, C, and D. This parallel frame floats on knife edges. Whatever force comes upon the weighbridges B and C is communicated through the crosshead D to the elbow lever E, the fulcrum of which rests on an anvil at the back of the hydraulic cylinder. The elbow lever communicates the force to the back centre of the steelyard lever above it. The poise-weights on the steelyard measure the forces. In tension tests the specimen, Figs. 8 or 9, Plate 164, is placed between A and C. For compression, Fig. 4, Plate 163, it is placed between A and B, and if it is placed between C and F it is tested in deflection, Fig. 5. The crosshead A, being movable in the notched frame, can be adjusted so as to take long or short specimens either in tension or compression. Upon the ram there is a large nut which can be screwed up tight against the end of the hydraulic cylinder, so as to hold the straining frame out for an unlimited time independent of any leak-off of the water. This device, which enables one to keep the load upon a specimen all through the night or through a vacation, was first introduced for Professor Archibald Elliott, who put down the first 100-ton machine having this provision at the University College, Cardiff.

The torsion apparatus is placed at the back of the main fulcrum of the lever, as shown in Fig. 3, Plate 163. It is entirely out of the way, and has no connection with the machine except through the torsion specimen itself when it is in position. The torsion gear will exert a twisting moment of 224,000 inch-lbs., and will twist in two a bar of iron $2\frac{1}{2}$ inches in diameter.

The deflection apparatus is shown on Fig. 5. It has swivel supports to prevent indentation, and the presser-foot also has swivelling half-round pieces which spread the pressure over 6 inches of surface, while still allowing the specimen to bend freely; so that if the distance between the centres of the semi-circles is taken, the test is theoretically the same as if the beam were supported on knife edges at that distance apart, while injury to the section by too intense local pressure is prevented.

The steelyard of this machine has an arrangement of poise-weights which is a combination of the variable jockey-weight starting from the centre of the steelyard, as introduced by Dr. Kennedy on a 50-ton machine,* the first of this type, which he put down in his laboratory in Westminster, and of the solid poise ranging over both arms of a double-armed steelyard which the author has used for many years. This combination has been arranged to meet Dr. Barr's desire for a larger scale unit when measuring light loads, and has the effect of giving the same scale unit up to 100 tons, which was obtained on Dr. Kennedy's machine up to 50 tons, without materially lengthening the steelyard. When the machine is being used for loads up to 32 tons, the large poise-weight remains stationary at the short end of the lever, and acts merely as a balance-weight to the long end. The variable poise starts from the centre of the lever and travels over the long arm with a scale reading of 4 inches to the ton up to 32 tons. This poise-weight, shown at G on Fig. 1, Plate 162, has two removable discs H, Fig. 2, which reduce it by half, giving a scale reading of 8 inches to the ton up to 16 tons. When the specimen requires more than 32 tons of load, this second poise, G, is lifted clear away from the machine. The balance of the steelyard is not affected owing to the poise being lifted off the line of the fulcrum. The main poise-weight is then liberated from its fixing to the steelyard and engaged with the traversing screw, and travels over the whole range of the steelyard, giving a scale reading of 2 inches to the ton up to 100 tons. At the suggestion of Dr. Barr, these poise-weights ride upon three wheels, of which the two on one side have flanges working in a groove in the rail of the steelyard, to keep the poise from wavering sideways, and a plain single wheel on the other side to support the poise vertically, thus forming a "geometrical guide." There are two scales on the steelyard, one for use with the large solid-poise and the other for use with the variable poise. The poise-weights carry vernier scales, which, at the suggestion of Dr. Barr, are attached by hinges to the poise-weights, and rest by their own overhanging weight in V grooves on the scale-bar. This insures that the vernier scale is always lying close up to the marks of the main scale, without the possibility of being injured from want of clearance by the vibrations of the steelyard following upon the fracture of a test piece.

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* "Engineering," 12 Sep. 1890, pages 304, 305, and 310.

The accumulator has a variable load consisting of ten 4-ton slabs, of which it can deposit any number up to nine on the base, and carry up the remainder. The slabs which it is desired to load on are, at the suggestion of Dr. Barr, hung from the top weight by three rods. This arrangement has been adopted not only on account of its advantages in connection with the testing machine, but to enable the accumulator to be used in connection with other pieces of apparatus, and to increase its value as an apparatus upon which efficiency tests under a great variety of circumstances may be made. In Fig. 1, Plate 162, the accumulator is shown standing on the floor level, but in the laboratory its foundation is sunk 7 feet.

Fig. 6, Plate 164, shows a shearing apparatus capable of dealing with specimens in single shear up to 2 inches square. The faces of the knives are kept close by a roller without undue friction. When a column is being tested, it is important to prevent the weighbridge B, Fig. 1, from wavering in any direction, and for this purpose there is a roller stay, shown in Fig. 7, Plate 164, on the arrangement which was first put in practice by Dr. Kennedy. It is formed by two brackets bolted to the sides of the gantry, and stayed together at the top so as to form a rigid framework. The crosshead has planed lugs upon it, and between those lugs and the stay there are both vertical and horizontal rollers R. The rollers are held between roller-paths on the lugs, and the roller paths on the stay.

The roller-paths on the stay are formed at the end of cylindrical pieces which fit in bored holes in the stay, and can be very gradually adjusted forward by screw bolts made with taper sides, and acting upon them like taper cotters. By means of this adjustment the roller-paths are set so that the rollers are just held, free from shake, between the compression crosshead and stay, and this is enough to restrain the crosshead from wandering during the light loading at the beginning of a compression or transverse test. But when the pressure becomes severe, the rollers are set up in the following manner. It is seen at the beginning of the test that all the rollers are bearing fairly and uniformly tight between the roller paths; when the test has proceeded to a few tons of pressure, the rollers are again felt round by the fingers, and it will probably be found that the crosshead has begun to bear hard against the rollers at two sides, and has left the rollers at the opposite sides with shake that can be easily felt. This indicates that the tendency of the crosshead is to depart from the line which previously brought it in contact with those rollers, and in order to restore it, the rollers that have lost touch are not themselves set up, but the opposite rollers to the slack ones, namely, the rollers against which the pressure is bearing, are set up until the crosshead is brought into touch again with the slack rollers, and thus restored to the position from which it was tending to depart. This takes up the spring of the stay, and it will probably not require any more attention throughout the test. In this way the end of the test piece is restrained from wandering away from the centre line of stress, and with no other friction than that of smooth rollers on smooth paths which have no direct pressure upon them, but only that pressure which is due to unsymmetrical yielding of the piece.

A horizontal testing machine cannot be verified in the same simple and direct manner as a vertical machine, merely by hanging dead-weights to the back centre. It has to be proved by careful measurement of the fulcrum distances; but, in order to ascertain that the fulcrums are all bearing fairly on their supports with clearance from any false bearing, the machine can be proved by means of powerful springs.

Fig. 8 shows a helical spring 8½ inches diameter made of 1½-inch diameter round steel with twenty-one coils, giving an elastic stretch of 15 inches with 7½ tons. A pair of these springs may be used yoked together side by side for testing both the accuracy and sensibility of the machine up to 15 tons. Each spring is hung vertically with standard weights suspended to it, and the extension of the spring is carefully measured by three pairs of points round the circle, the springs being then put into the horizontal machine and stretched until the measurement of the extension round the average of the three places is what it was when supporting the imperial weights; if the reading on the steelyard records the same weight, and retains its sensibility, the machine is proved not to be riding upon false bearings. In trying these large helical springs to their utmost capacity, they were loaded until they fractured at the hooked ends exactly as shown on Fig. 8. This was at 7¼ tons of load, but when screwed plugs were inserted, as shown on the lower view, the springs would carry 7½ tons each without failure, together giving an elastic stretch of about one inch to the ton.

A photograph of the machine taken in position is shown on Plate 165.

In conclusion, the author is sensible of the honour of the selection of his firm's machine for a laboratory bearing the great name of James Watt, at a University which was the first to establish a school of Engineering in Great Britain, and for a Professor of such distinguished ability and so thoroughly skilled in the practice of testing as Dr. Barr.

The Paper is illustrated by Plates 162 to 165.

Discussion.

The Chairman said the Paper was particularly interesting as describing a machine which had peculiar mechanical beauties, if he might use that expression, and also as representing the long accumulated experience of the author. He asked them to accord Mr. Wicksteed a hearty vote of thanks for his Paper.

Professor Archibald Barr said that many years ago he had committed himself to the opinion that a vertical machine was better than a horizontal one. He still held to that view as a principle, but this new type of machine introduced so many and such great conveniences into the modes of testing different kinds of specimens, that he came to the conclusion that the handiness of the machine was more important than the advantage that a vertical machine gave, more especially as they had side by side with this machine one of Mr. Wicksteed's 10-ton vertical testing machines, which illustrated the vertical type and could be used as an aid to the standardising of the horizontal machine. He noticed that his own name appeared rather frequently in the Paper. He thought much too frequently, because he felt that he could apply to himself here the scriptural remark that other men had laboured, and he had entered into their labours. He had entered into the fruit of their labours at least.

He believed that this machine, which had been installed within the last month, was the most perfect machine that had yet been built, and he was proud to have it in his laboratory. He thought they should recognise that they had in this machine the results of the labours of Mr. Greenwood, Mr. Kirkaldy, and Professor Kennedy. Professor Unwin had also done much to perfect the testing machine, and, with the benefit of the suggestions of Professor Elliot as stated in the Paper, they had the united results of experience of those best qualified to speak and act upon this matter. The author had given a most lucid description of the chief features of novelty in the machine. The main principle had already been described in "Engineering" *

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* "Engineering," 12th September 1890, page 310.

(Professor Archibald Barr.)

and elsewhere. There was one point upon which he might remark. Mr. Wicksteed said that upon his suggestion he had put the poise-weights on three wheels. He could wish that it was more common among engineers than it was to avoid redundancy of support or of guidance. He would like to say that whatever he had done in the way of insisting on non-redundant guidance was the result of the strong advocacy of that principle by Lord Kelvin and by his late master and friend Dr. James Thomson. He thanked Mr. Wicksteed for the trouble he had taken to meet their requirements, and he thought he was to be congratulated on having a machine which was second to none in the world.

Mr. ARTHUR GREENWOOD congratulated their friends Mr. Wicksteed and Professor Barr upon the very admirable machine they had devised between them, and also on their having returned to the true faith. Many of them began with vertical machines, for the reason that Professor Barr had mentioned. The one his firm exhibited in the 1862 Exhibition was a vertical machine, but along with the late Mr. Kirkaldy they came to the conclusion that a vertical machine was far too limited in its scope. Mr. Kirkaldy about twenty-five years ago adopted a horizontal machine, and the machine that the author had just described embraced most of the good points of that machine and some that had been added since. The arrangement for testing the machine by means of springs would be useful to show that the weigh-beams were on their true bearings; but whether it would be quite as good for testing the accuracy of the machine was, he thought, open to question. It would be easy to arrange another elbow lever, so as to prove it by dead-weight as was done on the Kirkaldy machine.

Professor W. CAWTHORNE UNWIN congratulated Mr. Wicksteed on the extent to which by gradual improvements he had increased the handiness of his testing machine. In the horizontal machine, as he has now constructed it, there was the greatest facility for making a succession of tests of different kinds with the least trouble in changing the shackles. After a great deal of experience, he had come to the conclusion that there was no absolutely best testing machine. Every type of testing machine had some advantage not present in others. After some months' use of a machine in which the load indication was taken from the pressure in the hydraulic straining cylinder (a 60-ton machine), he had come to the conclusion that in that type of machine the sources of inaccuracy could be eliminated, and that it was an extremely convenient machine. The one special advantage of the horizontal machine was that it could be so constructed as to take in specimens of any length. But it was only rarely that very long specimens had to be tested. He thought that in the case of horizontal machines it was desirable to have a special bell-crank lever, such as was provided in Werder machines, for calibrating the machine by a dead-weight. He did not think that the use of spiral springs for calibration was satisfactory. A spiral spring was used because with it a rough measurement of elongation sufficed. But it was better to use a simple straight elastic bar, and to measure the elongation with an accurate micrometer. With such a bar the machine could be tested not to 5 or 10 tons only, but up to the whole capacity of the machine, the elongations being rigidly proportional to the loads.

They had as yet no engineering laboratories, which could compare in equipment with some of the laboratories on the Continent and in the United States. Further, putting aside merely commercial testing, they were very much behind other nations in the prosecution of research work in testing. Abroad not only were laboratories provided, but the time and the means for prosecuting a very large amount of the most valuable work of research were secured to those in charge of them.

The CHAIRMAN said the time had come when the discussion must be closed. He thought a very important point was the utilization of machines of this class for research work. He had had occasion to refer to this matter at the opening of the James Watt Laboratories on Tuesday last, and hoped that some means would be devised by which the machine described and other parts of the laboratory equipment would be rendered available for original research. He quite shared

(The Chairman.)

Professor Unwin's views on this subject, and also on the advantages of using a standard bar in place of a spring in testing the accuracy of a horizontal testing machine. He believed, however, that one of the reasons for using the spring was to enable some motion to take place in the parts of the machine during the test. It was desirable that it should be tested with all the parts free. There was required a slight oscillation on the levers, and not merely a very small movement such as would result from the use of a bar alone. It had occurred to him that possibly the combination of the two methods might meet Professor Unwin's views and the desires of those who wished to have a free machine, the elongation of a standard bar being used as the measure of the pull applied, but this pull being exerted through a spring connection so as to give the parts of the machine freedom of movement.

Mr. WICKSTEED, in reply, thanked the President, Professor Unwin, and Professor Barr, for their suggestive criticisms. He quite agreed with Professor Unwin that testing the accuracy of the machine might best be done with a bar and micrometer.

In order to thrash out the question of the proving of the machine, he would mention another and very great worker in this line whose name had not been mentioned by Dr. Barr, namely Mr. Thomas W. Traill, Fleet Engineer. After his firm had made their first horizontal machine for Dr. Kennedy, one very much like it was ordered from them for Lloyd's Proving House at Glasgow, which was under the superintendence of Mr. Seedhouse. Mr. Traill taught him how to prove his testing machine by measurements. The system of proving by measurement had been adopted by Mr. Traill, and used by the Board of Trade under his superintendence. Mr. Traill first of all tried the sensibility of the machine, until he was able to pull it with a little spring balance on the short end of the machine. He then had the levers pulled down and laid on surface plates, and had all the knife-edges tried for parallelism with scribing blocks and gauges. He taught him how to bring all the knife-edges to the side of the lever where they were visible, and to have the sides of all the levers planed and the knife-edges run through in order to bring them to a plain surface. He believed that the testing machine could be absolutely proved by measurements, but when they had been looking for the thousandth part of an inch they did not know that they were correct to a whole inch. They might have made a mistake in the multiplication of the levers and be weighing 75 tons instead of 100. It was that which they wanted to prove with the springs. Also when the springs were put into the machine, they found whether the machine retained its sensibility with a load of 15 tons, or brought any of the knife-edges to bear on false bearings. This machine, following Board of Trade regulations, had a 4-inch fulcrum distance, and by making proper arrangements the distance could be measured within one-thousandth of an inch. This gave a possible error of 1 in 4,000 or $\frac{1}{40}$ of one per cent.; an elbow-lever and dead-weights would not ensure greater accuracy than that.

In the Werder machine the case was quite different, because the fulcrum distances were only $\frac{3}{16}$ inch apart, and an error of one-thousandth of an inch in the measurement gave an inaccuracy to the machine of 1 in 186 or more than $\frac{1}{2}$ of one per cent.

A REGENERATIVE ACCUMULATOR, AND ITS APPLICATION FOR USING EXHAUST STEAM.

By M. A. RATEAU, of Paris.

(*Translated from the French.*)

The new apparatus referred to in this Paper is intended to allow, in a turbine or any other motor, the use of the exhaust steam from machines having intermittent action, such as winding engines or the reversible engines of rolling mills. Engines with intermittent action are well known to be defective in respect of the satisfactory use of the steam, caused by condensation within the cylinders. This inconvenience has no doubt been to a small extent remedied by compounding and also by condensing; but the advantage gained is much less than can be obtained by using the steam at about atmospheric pressure in a turbine provided with a condenser.

The Hon. C. A. Parsons has already urged the use of turbines with low steam-pressure, attached to continuously-running steam engines. For instance, if we take a winding engine using 45 kilogrammes (99 lbs.) of steam per B.H.P. (*utile*), which is about the minimum for non-compound engines without condensation, these 45 kilogrammes of steam are sufficient to give, in a steam turbine coupled to a dynamo, an electric power of at least two horse-power; by the application in this case of the regenerative accumulator system, two horse-power is added for each one horse-power of the winding engine.

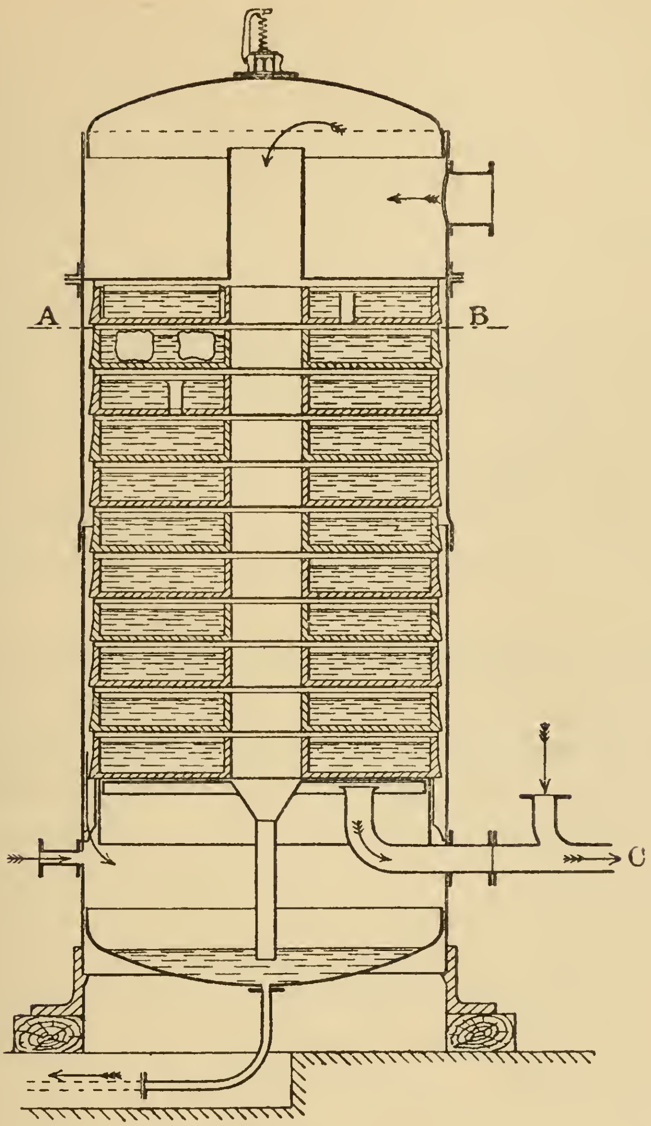
The difficulty which this apparatus solves is the following:—

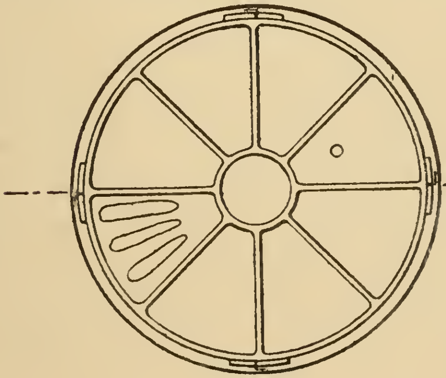
The turbine requires to be supplied with a continuous flow of steam, whereas the engine working intermittently delivers it at more or less regular intervals of one or two minutes. A reservoir is therefore required between the two engines. An ordinary reservoir would have excessive dimensions, whilst with the apparatus about to be described this excessive size is avoided, and the cost of erection is relatively small.

This apparatus, which may be called a "regenerative steam-accumulator," serves the purpose of a reservoir. The solid and liquid materials, which it contains, form a storage in which the steam gathers and condenses when arriving in excess, and subsequently re-evaporises during the period when the main engine slackens or stops. The variations in temperature necessitated by the condensation and re-evaporation of steam correspond to the small fluctuations of pressure in the accumulator. The pressure rises while the apparatus is filling, and falls while it is being emptied. The amplitude of these temperature and pressure oscillations is not great, 3° to 5° C., and 0·10 to 0·15 kg. per cm^2 (1·4 to 2·1 lbs. per square inch). This variation can be limited to any desired range by designing the apparatus sufficiently large in accordance with the periods of running and standing of the main engine.

Calling the variation of temperature t (which is in practice 3° to 5° C.), the weight of materials forming the storage of heat P, and the mean specific heat of these materials G, the quantity of heat absorbed by the accumulator and restored by it at each period is $P\ G\ t$ calories; and the quantity of condensed vapour, then vaporised, corresponding to this number of calories, is equal to about $\frac{PG\,t}{L}$, L being the latent heat of the steam.

The apparatus consists, as may be seen from the illustration (page 947), of cast-iron annular basins placed one above the other, inside a cylindrical vessel of sheet iron. The steam, which enters the vessel by the pipe near the top, reaches the basins by the central channel. The portion which is not condensed, as well as that which is re-evaporated, descends along the lateral partitions of the vessel, and reaches the pipe C leading to the low-pressure machine.





Section at A. B.

The water carried away by the steam separates out in the upper chamber and falls, first through holes in the top plate, thence from basin to basin by the passages in the overflow to the bottom of the vessel, whence it is discharged by the small pipe, having an automatic steam-trap. The basins are thus always covered with water.

The apparatus is completed with a safety valve and an automatic steam-valve for assisting the turbine by steam direct from the boilers.

By means of this accumulator it is possible to obtain, in an ordinary-sized winding-engine plant, an additional motive power of about 500 H.P., with no expense but the cost of installing the turbine and accumulator, which is not great.

An application of 250 H.P. is now in course of erection at the Bruay Mines in the North of France, and will be working in a few months.

The Paper is illustrated by 1 Fig. in the letterpress.

[Note.—*The discussion on this Paper was postponed until after the following Paper by the same author had been submitted to the Meeting.*]

EXPERIMENTS ON THE ESCAPE OF STEAM THROUGH CIRCULAR ORIFICES.

By M. A. RATEAU, of Paris.

(*Translated from the French.*)

The design of steam turbines depends upon the knowledge of the laws which determine the escape of steam through converging or converging-diverging orifices. In order to verify exactly the formulæ for the escape of steam, the author undertook, in 1895–1896, at St. Etienne, a series of experiments on this subject, according to a method which gives the greatest possible precision. A short indication of these experiments has been given in the report on steam turbines which the author had the honour to present last year at the International Congress of Applied Mechanics in Paris. But at that time he had not yet completed all the calculations of the results of his experiments, whereas now he is able to give an account of the results. They differ a little from those the author provisionally announced at the Congress of 1900.

Those investigators who experimented before and since the author, namely, Minary and Résal in 1861, Peabody and Kunhard in 1890, Parenty in 1891, Miller and Read in 1895, and Rosenheim in 1900, have all used the same method, which consists of condensing in a surface condenser the steam, which escapes by the orifice for a sufficiently long period, and then weighing the condensed water. But this method, beyond being very laborious, cannot give great precision, because in the first place it is very difficult to keep the initial steam-pressure (*pression d'amont*), P, constant during the whole of the experiments, and the steam, being never absolutely dry, the water which it carries with it is weighed with the condensed water, so that the results found must be generally over-estimated.

The author therefore proposed to remove these causes of error so as to obtain exact results within two-thousandths, and to use, besides, sufficiently large orifices to deliver up to more than 900 kg. of steam per hour.

He has reached the desired result by condensing the steam in a stream of water with the use of an ejector-condenser, and by measuring the total yield of water per second and the initial and final temperatures of this stream. Thus he was able to make all the readings at the same moment, as soon as constant conditions were obtained; and each experiment did not last more than one or two minutes. It has been possible thus without much trouble to make more than a hundred and forty observations under the most varied conditions.

Fig. 1 represents diagrammatically the apparatus employed. A is the ejector-condenser which receives steam through the pipe B, and cold water by the pipe C. The hot water containing condensed steam escapes by the pipe D into the sheet-iron chamber E, where the air separates out; then it goes out through the converging orifice F at a pressure measured by the water gauge *hh*.

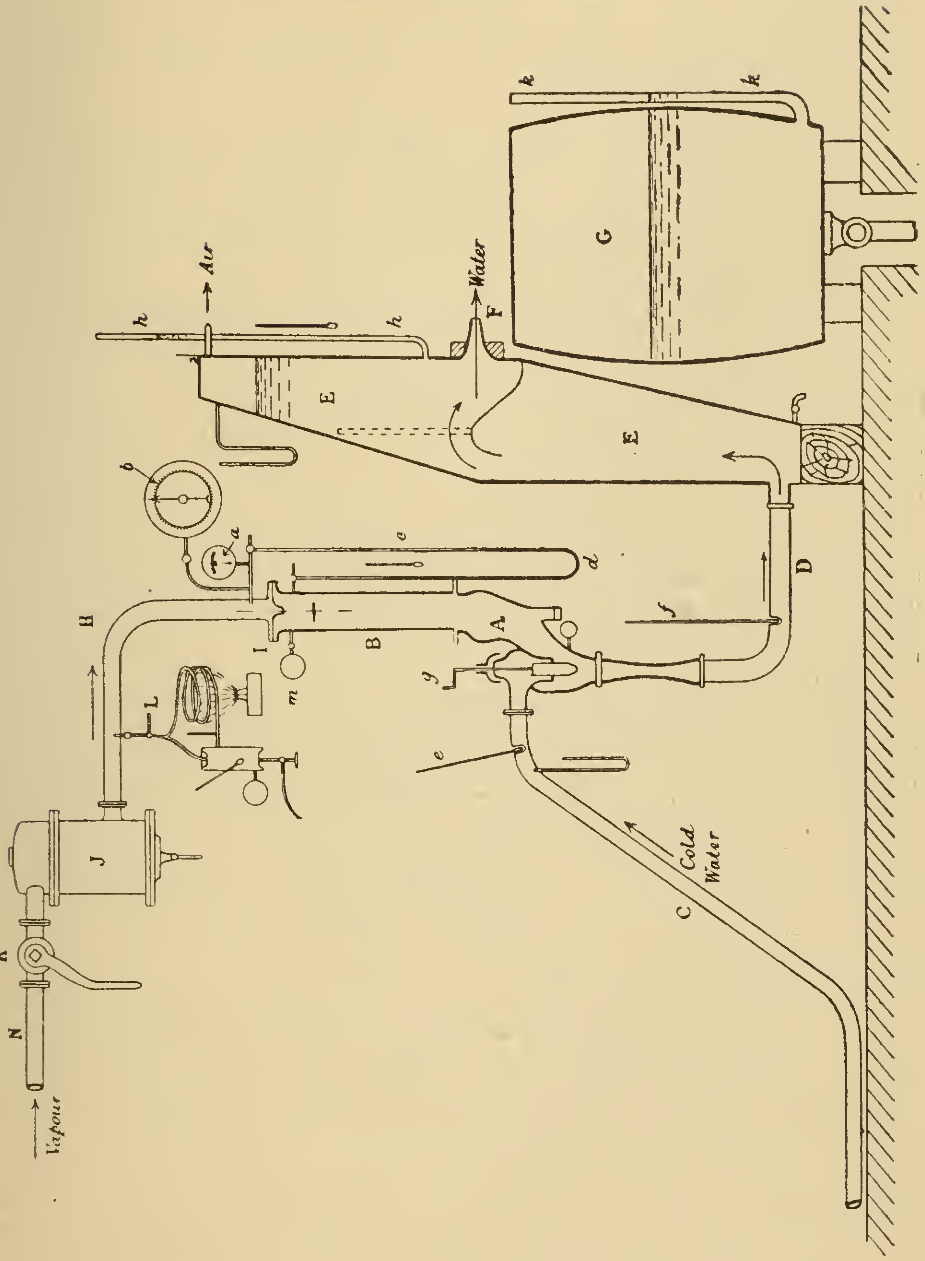
The rise in temperature of the water is measured by the thermometers *e* and *f* graduated to twentieths of a degree, and previously calibrated in comparison with a Baudin thermometer.

The nozzle to be tested is placed within the pipe at I. It receives the vapour through the pipe H, 50 mm. diameter, and throws it into the large pipe B of 120 mm. diameter. The initial pressure P (*à l'amont*) was measured by one or other of the gauges *a* or *b*. The resultant pressure *p* (*à l'aval*) was measured by either the metallic pressure-gauge *m*, or the mercury gauge *cd*.

The steam, arriving from the boiler by the pipe N, rushes with centrifugal force into the separator J, on account of the partial vacuum therein; nearly the whole water carried over falls down

Fig. 1.

Diagrammatic Sketch of Apparatus.



there, and the small quantity remaining can be measured by the specially arranged apparatus L.

The author was thus assured from the beginning of his experiments that the quantity of water passing the separator never exceeded two to three-thousandths, and as the error due to this method could not exceed half of this amount, or an insignificant figure, he has neglected it.

The pressure before passing the nozzle could be regulated at will by means of the cock K; a special valve, actuated by the crank g, enabled the pressure p (*aval*) to be fixed at any desired amount above the lowest pressure caused by the ejector-condenser. The author has thus been able to operate through a long range of pressures, from 0·10 to 12 kg. per cm.^{2} (1·4 to 170·6 lbs. per square inch). The rate of flow through the water-orifice F had been previously measured with great care by means of the barrel G graduated along the tube KK.

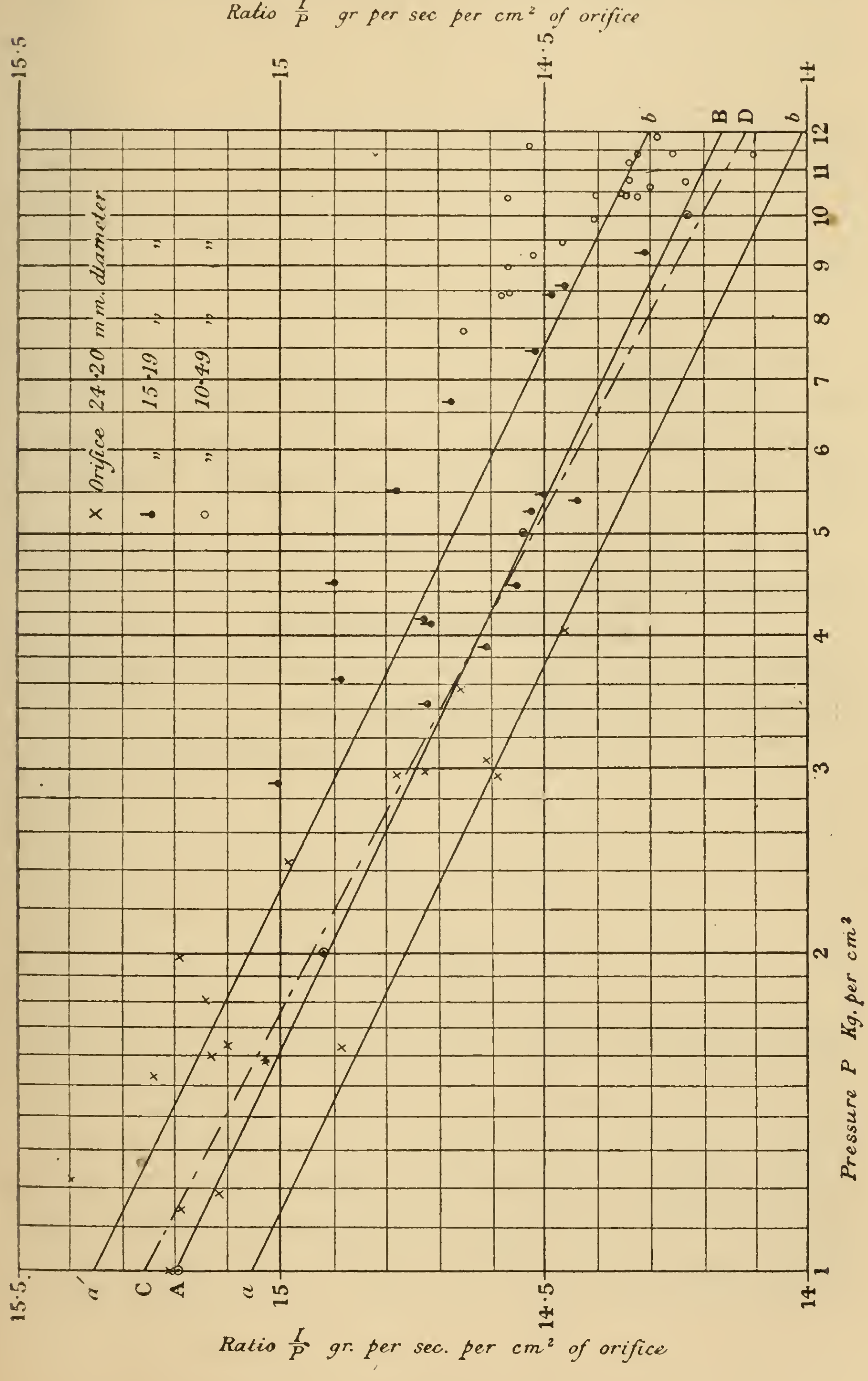
The author has experimented successfully upon a thin-walled orifice, and upon three converging nozzles having respectively a diameter at the narrowest part of 10·49, 15·19 and 24·20 mm. (0·41, 0·59 and 0·95 inch).

Without entering into detail of the figures involved in these calculations, Fig. 2 gives in graphic form the results obtained with converging orifices, in all cases where the subsequent pressure p (*aval*) was less than 0·58 of the initial pressure P. The points indicate the ratio $\frac{I}{P}$ rate of consumption in grammes per second and per cm.^{2} of orifice, at the absolute pressure P (*d'amont*) in kg. per cm.^{2} for different values of P.

There are fifty-nine results which approximate to the theoretical straight line AB, calculated from Regnault's tables by the thermodynamical formula, assuming that the mechanical equivalent of heat is equal to 425 kilogrammètres per calorie. The differences do not usually exceed 2 per cent. The mean of the results gives a figure seven thousandths in excess, when compared with the theoretical calculation. This difference may be due to the displacement of the thermometer zeros (of 1 to 2 tenths of a degree) during the course of the trials. It will be observed that this would not exceed 3·5

Fig. 2.

Comparison of Experiments on Converging Orifices and Theoretical Calculations.



thousandths, if one assumed for the theoretical calculation a value 428 for the mechanical equivalent E, which is now admitted; for the formula of the speed of escape includes $\sqrt{2\,gE}$ as a factor.

The scale of ordinates in the figure is contorted on account of the method of recording small differences. To show clearly the value of the differences, straight lines $a\ b$ and $a'\ b'$ have been drawn on Fig. 2. These differ from the theoretical line by one per cent. more and less respectively. The line C D corresponds to Grashof's formula

$$I = 15 \cdot 26\ P^{\,0 \cdot 9696}.$$

The correspondence between the theory and the practice is satisfactory. It is the same when the subsequent pressure p (*aval*) exceeds 0·58 P, in which case the consumption of steam depends on the two pressures p and P simultaneously, whilst the consumption depends on P only if p is less than 0·58 P.

In the latter case the consumption may be very exactly represented by the formula

$$I = P\,(15 \cdot 20 - 0 \cdot 96 \log. P),$$

I being the consumption in grammes per second and per cm.^{2} of orifice, and P the initial pressure in kg. per cm.^{2}

The Paper is illustrated by 2 Figs. in the letterpress.

Discussion.

The CHAIRMAN said that M. Rateau's second Paper was one which did not lend itself to reading. It was entitled "Experiments on the Escape of Steam through Orifices." He might say that the discharge of steam in connection with the design of steam turbines was a matter to which M. Rateau had devoted very great attention, and one in which he had carried out a large amount of experimental work. Any deductions at which he might have arrived were therefore worthy of every possible attention at their hands. He would now ask any gentlemen who were interested in these Papers to give them their views upon them. The first Paper dealt with a very ingenious means of utilizing the exhaust steam in such circumstances as M. Rateau had described.

Professor A. Stodola, of Zurich, said he would like to make a few remarks in regard to the statements which were expressed in the Paper. He thought that they had still much to do in the way of increasing the economy of the steam-engine, and especially of the steam-motor which needed to be increased very much in its efficiency. As to whether all the predictions would be corroborated by practice was still a question. Like Professor Schröter and his colleagues, he now took the opportunity, as representing Switzerland, of tendering his very hearty thanks for the kind reception which they had given them, and also congratulated them on the brilliant success of the great Congress which had been arranged.

Mr. Bryan Donkin, Vice-Chairman, said that they might call this apparatus a sort of heat or thermal unit fly-wheel, taking in heat and giving it out when required. With regard to the second Paper, it ought to be entitled "Experiments on the Measurement of the Quantity of Steam through Circular Orifices." The subject was brought before the Congress in Paris last year, the Paper being originally published in French, and he would strongly recommend engineers to study the original. Steam could be very accurately measured in bulk through orifices, if correct co-efficients were used. In his first Paper M. Rateau said the application of 250 H.P. was in course of erection at the Bruay Mines in the north of France, and would be working in a few months' time. It would be very interesting if he would kindly give them the results of these practical experiments.

M. Rateau, who replied in French, returned thanks for the reception of his Paper. He thanked the Chairman particularly for his kind words, and also thought that Professor Stodola's opinion on his (M. Rateau's) proposed system was valuable, because of the

(M. Rateau.)

authority which it acquired from his remarkable lectures on Applied Mechanics at the Polytechnic in Zurich. He was glad to see as Vice-Chairman of the Mechanical Section his friend Mr. Donkin, who was well known in France, as in all industrial countries, by his numerous Works, notably on the passage of heat through cylinder walls. He thanked Mr. Donkin for his remarks upon the two short Papers, and agreed with him that the steam accumulator was in fact a heat fly-wheel. He wished to take this opportunity of expressing his regret that he had not sufficient command of the English language, and had thus been deprived, on the previous day, of having the pleasure of taking part in the discussion on Steam Turbines. He would have then expressed his opinion that steam turbines existed for the utilisation of low-pressure steam. He himself had carried out in France for some years researches on steam turbines, and he followed with interest the progress of the Parsons Turbine. It would have given him pleasure to signify his respect for the persevering energy shown for nearly twenty years by the Hon. C. A. Parsons in bringing this question of steam turbines to a successful issue. The numerous and considerable difficulties raised in the problem of the industrial application of steam turbines were well known; and one must admire the ingenuity with which they have been conquered in the Parsons turbine. Referring to the accumulator, he explained that the diagram (page 947) showed accurately the apparatus which had been fitted to the winding engines at the Bruay Mines, and said that he would like to communicate the results of its working at a future date.

The Chairman hoped that after some experience had been gained with the winding engines at Bruay, M. Rateau would contribute a Paper giving the results. The device described was particularly interesting in its application to engines such as winding and reversing rolling-mill engines. He asked them to accord a hearty vote of thanks to M. Rateau for his Papers, and for the explanations he had given.

Communication.

Mr. **Michael Longridge** expressed regret that there had been no time for a discussion on this Paper, as he would have liked to hear the name of Halpin as well as that of Parsons mentioned in connection with M. Rateau's ingenious combination; for if the Parsons' turbine was necessary to utilise the low-pressure steam from the reciprocating engine, the thermal storage system, associated in this country at least with the name of Mr. Halpin, was equally necessary to provide the steam while the reciprocating engine was at rest. The combination was a very happy one and calculated to effect some saving in colliery working, provided the thermal storage vessels were properly designed. It was a question whether an independent condensing plant applied to the winding engine would not in many cases yield nearly as good a commercial result.

M. **Rateau** wrote in French that he had read with interest the reports of Mr. Halpin's system of Thermal Storage, and he thanked Mr. Longridge for having drawn his attention to these. Mr. Halpin had proposed to remedy the deficiency found in central electric stations, by installing steam generators capable of completing the maximum power required at the station during a very short period of the day; for this purpose he added to the boilers vessels full of cold water (which simply formed annexes to the boilers), and he worked them at a pressure well above that necessary for the engines, so that these vessels constituted a heat fly-wheel capable of furnishing steam to the engines during a considerable time. In short, this was the development to the full extent of what had been already done in many places, by increasing the capacity of the boilers, particularly on locomotives and in ships, and thus producing steam in a boiler at a pressure 3 to 6 kg. per cm.^{2} higher than that which the cylinders required, and interposing a reducing valve between them and the boiler. The author's object was quite different. He proposed to utilise the low-pressure steam coming from the exhaust pipe of an engine working irregularly; and for this purpose he interposed an accumulator between this engine and the low-pressure steam turbine. He saw nothing in Mr. Halpin's system which corresponded to the utilisation of low-pressure steam by an engine fed by steam from another.

POWER REQUIRED TO DRIVE A MARINE-ENGINE WORKS.

By Messrs. JAMES CRIGHTON and W. G. RIDDELL, of Glasgow.

It is not the intention of the authors to attempt to describe a model engine-works or driving plant, but rather to enumerate and show the result of a few improvements which have been adopted by the firm with which they are connected.

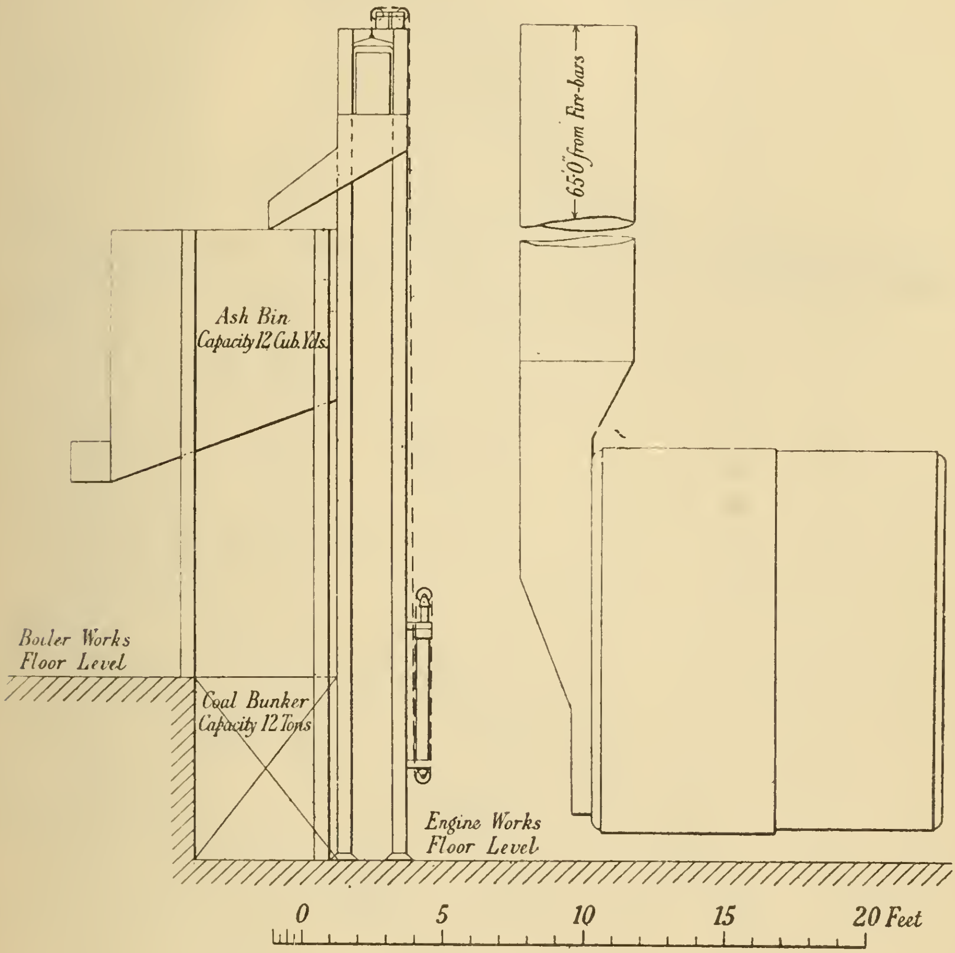
About three years ago it was decided to re-arrange the works in a thorough manner, and to fit up a new power installation. The works had gradually grown during upwards of thirty years, and most of the buildings were in excellent condition and in no need of reconstruction. The problem to be solved then was how to lay down an economical driving plant which would conform to the existing conditions, and which would not lead to an unnecessary sacrifice. At that time the motive power of the works consisted of one marine type boiler working at 80 lbs. pressure, and supplying steam to three vertical compound engines for driving the machinery, and one vertical compound engine for lighting purposes. The points in favour of so many units were the saving in steam when running one or two machines at night, which might be driven by one of the small engines, and also the fact that in the event of a breakdown of one engine, the other parts of the works were not affected.

It was, however, decided to put in one engine capable of driving and lighting the entire works, and to meet the difficulty of late work, by driving those machines, which experience showed were the most likely to be needed at night, by motors which could be connected with current from the Glasgow Corporation. The engine was made to a simple design, in order to make the risk of a breakdown very remote. A cylindrical marine boiler, designed to work under either forced or natural draught, was selected as the most suitable type, and has proved itself both economical and reliable. The position of the power station was fixed to a certain extent by circumstances.

The works are situated in a busy part of the City of Glasgow, where ground is costly and economy of floor space essential. There is no direct communication with any railway, so that all material has to be carted to and from the works. Close proximity to the street was therefore an important factor in settling the position of the boiler. The position chosen was between the engine and boiler departments, and as the difference in the floor level of these departments is about 6 feet, the boiler was placed on the lower level and the coal tipped over into a bunker in front of it, Fig. 1. The ashes were returned by a hydraulic hoist to a receiver raised above the higher level, under which a cart might be filled automatically. The engine (pages 962–3) was placed as near the boiler as possible with the crank-shaft parallel to two of the main lines of shop shafting. Two dynamos were laid down for lighting and driving purposes; and these and the two lines of shafting were connected to the main engine shaft with belts, and all so arranged as to be easily disconnected. Motors were laid down to drive all outlying shafting.

The existing conditions having been treated in a general way, the driving plant will now be described in detail. The boiler, Figs. 1 and 4 (pages 961 and 964), is of the cylindrical marine type, 13 feet 6 inches mean diameter by 12 feet 6 inches long, and is fitted with three Morison suspension furnaces 3 feet 1 inch inside diameter by 8 feet long. The working pressure is 200 lbs. per square inch. The firebars are 5 feet long, and the grate area is 46·2 square feet. There are three separate combustion-chambers and 316 tubes 2½ inches external diameter by 8 feet long. The total heating surface is 2,040 square feet, being 44·2 times the grate area. The height of the chimney above the firebars is 65 feet. A 60-inch fan (page 962) is provided to blow air into the furnaces through fronts of the Howden type, and the boiler tubes are fitted

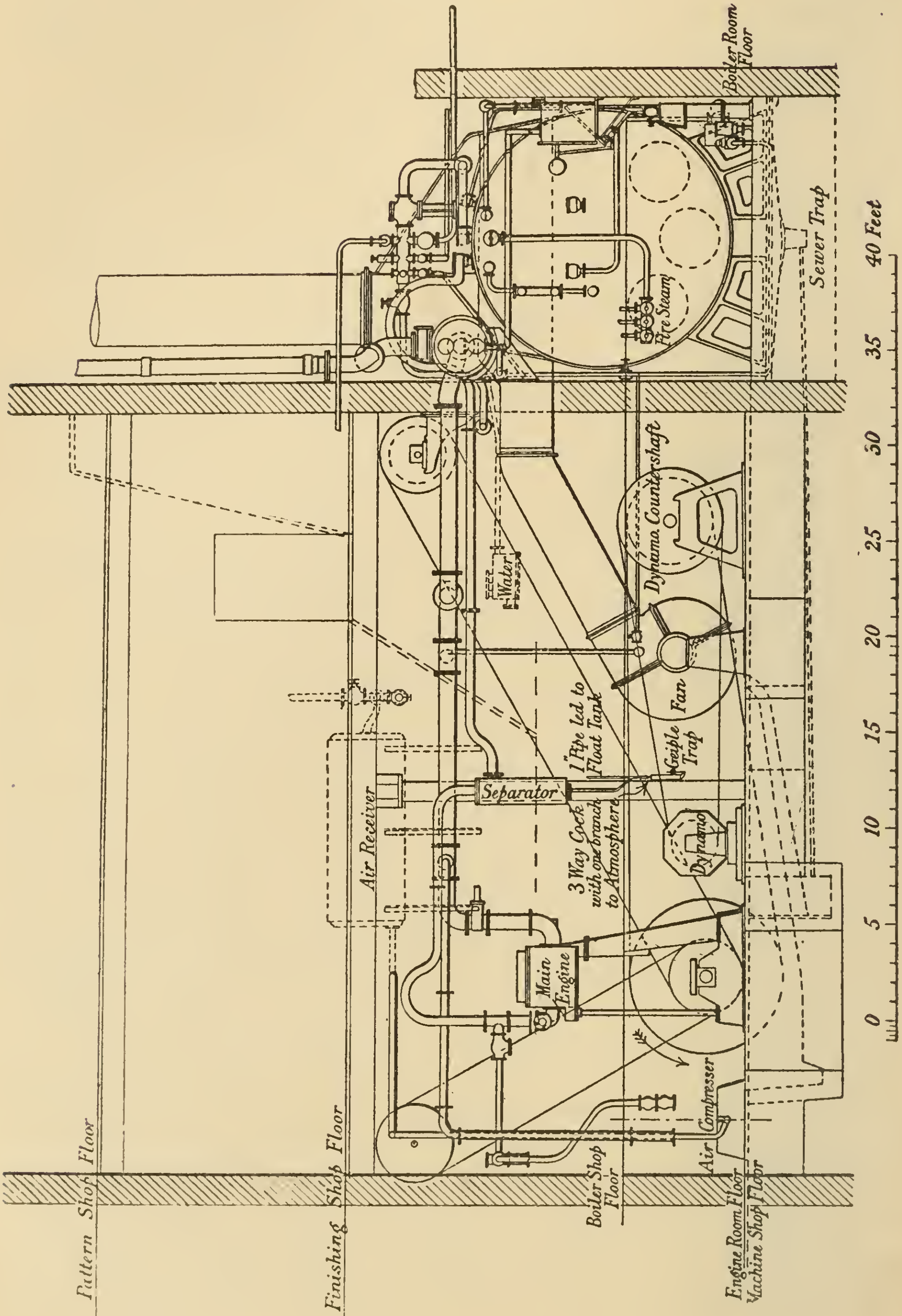
FIG. 1.—*Arrangement of Boiler and Stokehold.*



with retarders. The boiler is covered all over with non-conducting material, and the loss from radiation is so small that 3 to 5 cwts. of coal is sufficient to keep up the steam pressure during the night when the engine is not working. A Craig's combustion tester is kept in the boiler room, by means of which the percentage of carbonic acid gas in the up-take may be read at sight, and the air supply reduced

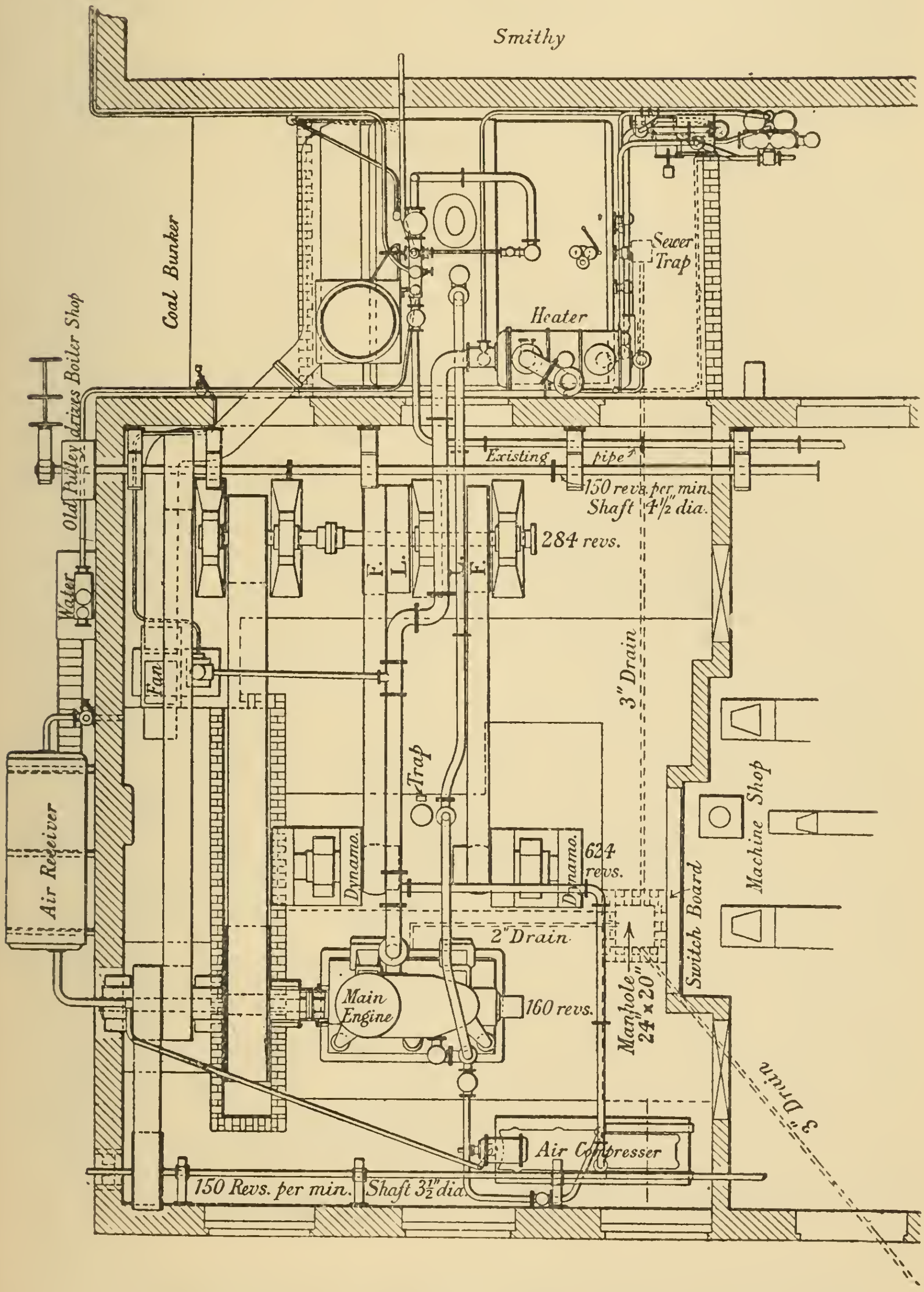
Arrangement of Power House.

Fig. 2.—Elevation.



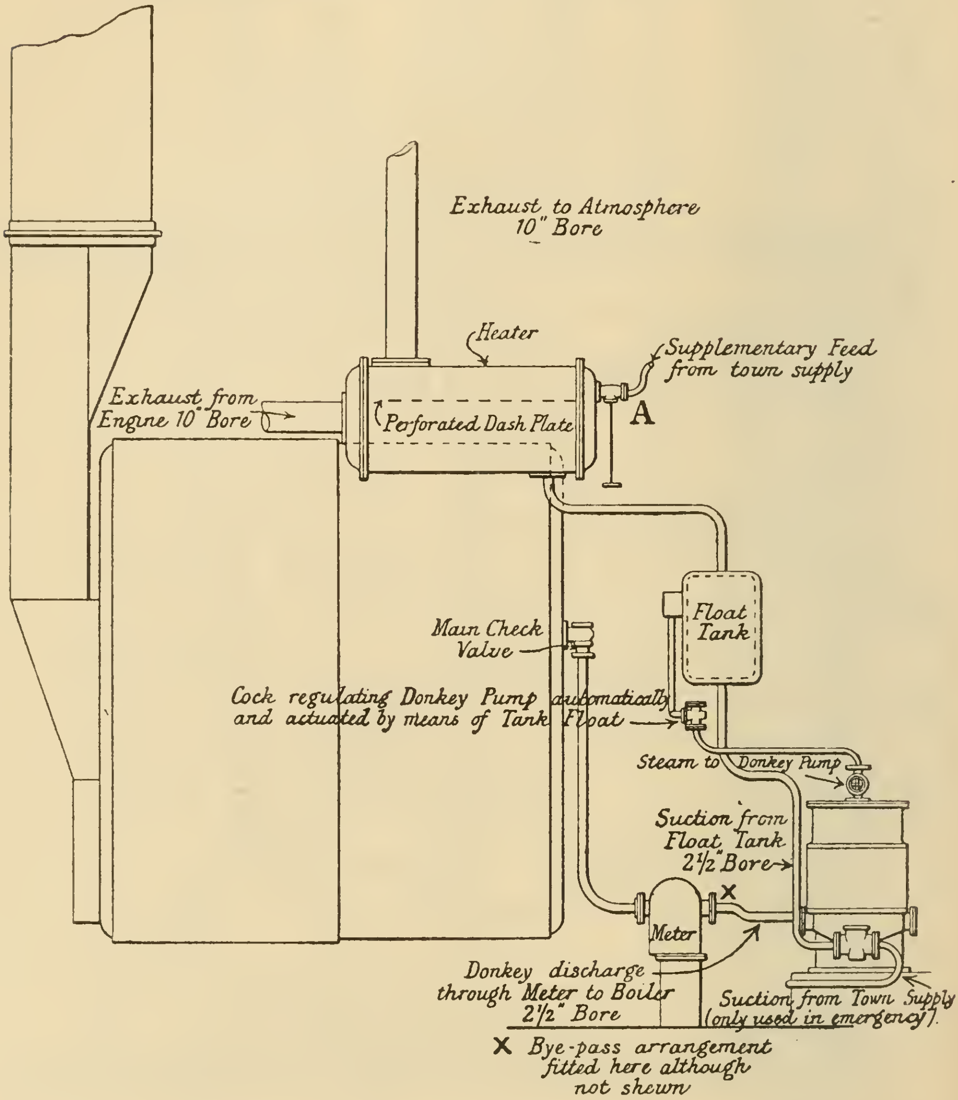
Arrangement of Power House.

Fig. 3.—Plan.



to the point where efficiency begins to decrease. The feed-water is heated by exhaust steam, and enters the boiler through a Kennedy water-meter at a temperature of 205° F. The arrangement is shown in Fig. 4.

Fig. 4.—*Diagram showing Exhaust-Heater and Main Boiler Feed Connections at Messrs. D. Rowan and Co.'s Works.*



Numerous evaporative tests were carried out with different kinds of coal. The coal and ashes were measured, and the capacity of the measure was frequently tested, and the water meter was read at regular intervals. It was, however, found that even the absence of a desire for phenomenal results did not prevent the weight of the coal burned at the tests from being apparently less than the weight passed over the weigh-bridge. The difference was sometimes as great as 5 per cent., after deducting coal used for keeping up fires at night and for lighting fires at the beginning of the week. Measuring was therefore discontinued, and the weight of coal passed over the weigh-bridge taken as the amount burned. The water meter was read at stopping time each Saturday, and continuous weekly returns showing the cost per 100 gallons of water evaporated were made up from the figures thus obtained.

The tabulated tests of the boiler were made when the alterations to the driving plant were incomplete, and the amount of steam required was greater than is used in ordinary circumstances. It is probable, however, that, owing to additions to the works and new machine-tools, the quantity of water evaporated at these tests will ultimately be required. Now that all the power in the works is derived from one engine, less steam is being used, and the rate of combustion per square foot is less and the efficiency slightly greater. Notwithstanding this, the tests taken at the higher rate of combustion have been used in this Paper as the basis for calculating the cost of power as, in course of time, the conditions prevailing at these tests will be the normal working conditions of the boiler.

Trials of the boiler were carried out for four consecutive weeks with a different kind of coal each week. The coal was tested daily during the four weeks with a Thomson's oxygen calorimeter. During the first week the cheapest quality of coal which would give the required amount of steam was used. This cost 8*s.* 10*d.* per ton, and goes by the local name of "washed singles." It had a low calorific value of about 10,000 B.T.U. per lb. The rate of combustion was fully 40 lbs. per square foot of grate per hour, and when burning this quantity great volumes of black smoke were given off.

"Washed doubles" or "nuts" was the next quality tried. It costs 1*s.* per ton more than "singles" and had a slightly higher calorific value, but its evaporative power was not worth the extra 1*s.*

The third test was made with "steam coal triping" at 10*s.* 6*d.* per ton. The great defect of this coal was the large proportion of fine dust contained in it. An air pressure of $\frac{5}{8}$ inch had to be maintained in the ash-pits in order to burn it quickly enough, and this carried the dust away before it was burned. It lodged in crevices of the smoke-box, where it took fire and did damage.

The fourth and last coal tried was steam coal at 11*s.* 6*d.* This coal had a calorific value of 14,320 B.T.U., and gave all-round satisfactory results. The cost of evaporation was slightly higher with this coal than with "washed singles"—7·49*d.* per 100 gallons against 7·36*d.* per 100 gallons, but this was more than saved in wages. One fireman was able to attend to the boiler all day when firing steam coal, but had to be relieved when firing singles, the rate of combustion being so much higher with the latter.

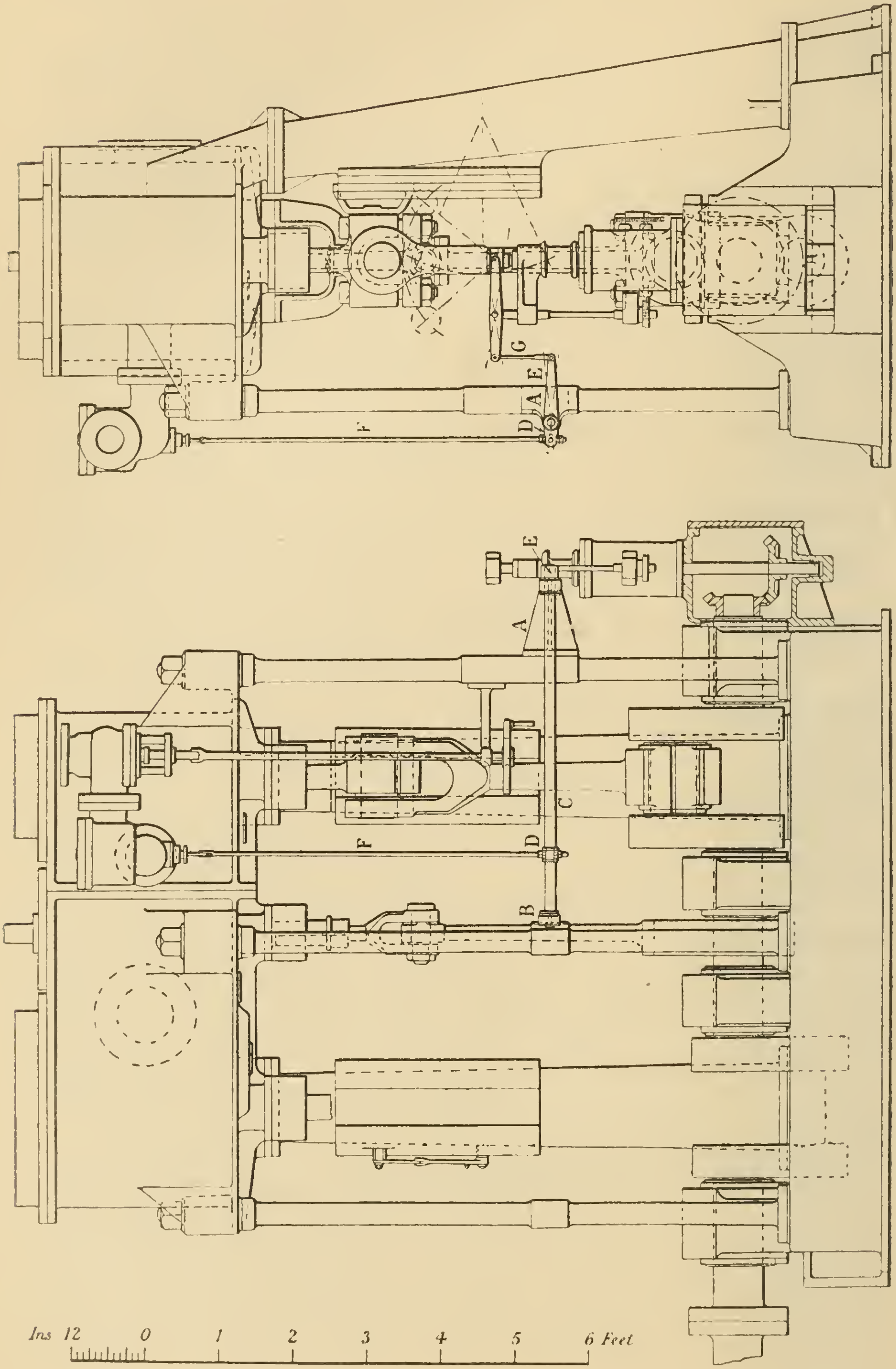
In Table 1 (page 967) a deduction of two tons was made in each case from the weekly coal consumption, when finding the rate of combustion per square foot of grate. This is the amount used for keeping up steam at night and lighting the fires at the beginning of the week. The total weekly consumption was the weight taken in finding the other figures. It may be added that, after allowing for the error in measuring the coal, an equivalent evaporation of 11·5 lbs. from and at 212° F. was frequently maintained for several hours at a time, but the losses due to stoppages for meal hours and cleaning fires reduced this to the figures given in the Table. The grate area of the boiler is 46·2 square feet and the heating surface 2,040 square feet. The feed temperature was 205° F., and the steam pressure 200 lbs. during all trials.

The engine, Fig. 5 (page 968), is of the vertical double-acting compound type, and is at present non-condensing. A cooling tower is being erected, but owing to its position in the centre of the works it could not be completed sooner without disorganising the establishment. The engine has cylinders 12½ inches and 23 inches diameter by 21 inches stroke, and works at 200 lbs. pressure per square inch.

TABLE 1.

Kind of Coal.	Washed Singles at 8*s.* 10*d.*	Doubles at 9*s.* 10*d.*	Steam Coal Triping at 10*s.* 6*d.*	Steam Coal at 11*s.* 6*d.*
Coal burned per week . . tons	47·15	46·25	40·4	37·3
Coal burned per square foot of grate per hour . . . . lbs.	40·5	39·7	34·5	31·4
Percentage of ash in coal . . .	15	12	16	8
Total water evaporated per week lbs.	715,000	713,300	715,400	715,000
Water evaporated per lb. of coal actual . . . . . lbs.	6·76	6·88	7·9	8·62
Water evaporated per lb. of coal from and at 212° F. . . . lbs.	7·16	7·29	8·36	9·13
Water evaporated per square foot heating surface . . . lbs.	6·55	6·47	6·58	6·55
Temperature of uptake . . F.	630°	635°	650°	617°
Air pressure in ash-pits . . inch	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{1}{2}$
Cost of carting away ashes shillings	10·6	8·3	9·7	4·4
Cost of fuel for evaporating 1,000 lbs. water . . . . . pence	6·99	7·65	7·1	7·14
Total cost of 1,000 lbs. steam, including cost of water, coal, and cartage of ashes . . . . . pence	7·36	8·02	7·46	7·49

Fig. 5.—*Shop Engine. Cyls.* 12½ *in. and* 23 *in.* × 21 *in.* 160 *revs.*



The cranks are placed directly opposite each other, and the slide-valves of both engines are actuated by one eccentric and one valve spindle. At present the exhaust steam passes through a receiver to the atmosphere, the receiver being so constructed that it could be easily converted into a surface condenser when the cooling tower is ready, and this is now being done. The feed-water meets the exhaust steam in the form of a spray, and is heated to 205° F. It then falls by gravity to the float tank of a Weir's feed pump, and is pumped through a Kennedy water-meter direct into the boiler. In the design of the engine simplicity of parts and ample bearing surface were aimed at in order to minimise, as far as possible, any risk of breakdowns.

The two main lines of shafting, Figs. 6 and 7 (page 970), are driven direct by means of belts from pulleys on the main engine shaft (pages 962–3). Another belt is taken from the fly-wheel on the engine crank-shaft to a countershaft, which countershaft in turn drives the electric generators. The generators are two in number, of the Schuckert type designed for 110 volts and an output of 70 kilos each, which may be used alternatively for lighting and power. From a series of trials it was found that the engine was developing 147·27 I.H.P. when driving the electric lights alone. This represented a mechanical efficiency at the generator terminals of 0·68, which may be considered fairly good, seeing that the engine was only working at slightly more than half load, and including, as it does, the losses in friction of the engine itself, dynamo countershaft, and dynamo.

In order to find the power absorbed by the line shafting in the works a series of trials was carried out. At the first trial only the line shafting and loose pulleys were run. The machines and countershafts were run along with the shafting at the second trial, and the final trial was made with the machines cutting at their normal rate. The average diameter of the line shafting in the works is $3\frac{1}{4}$ inches, and its speed is from 140 to 150 revolutions per minute. It runs in white metal self-oiling pedestal bearings spaced about 12 feet apart. The total length of line shafting in the works (page 970) is 2,300 feet, and the weight is 37 tons 8 cwts. 2 qrs.

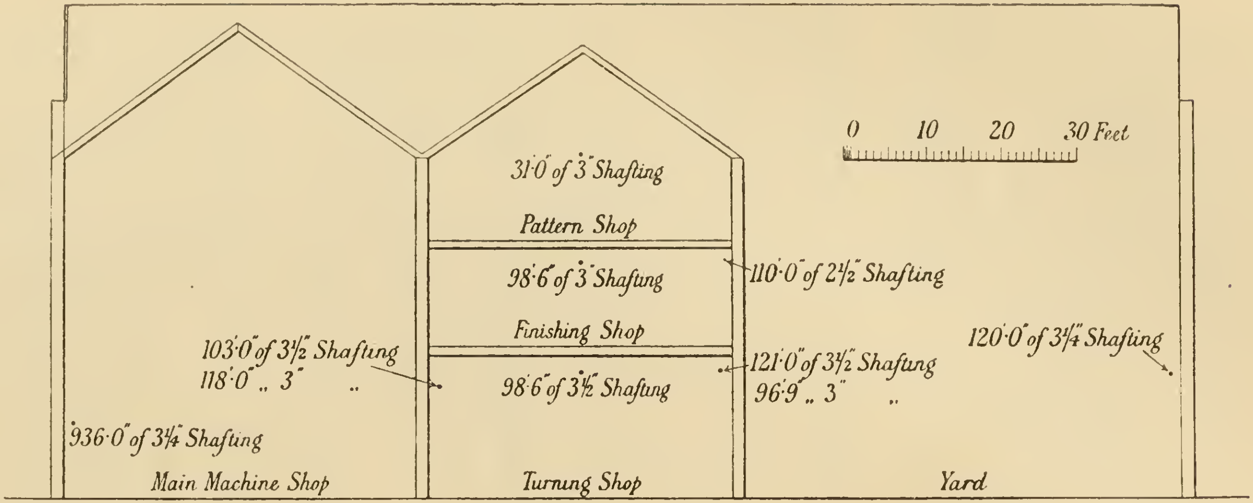
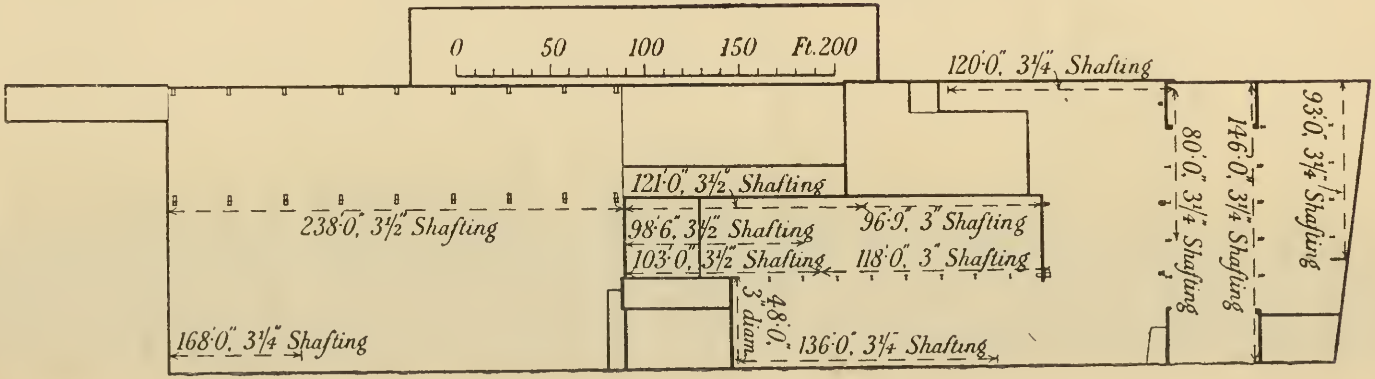


FIG. 6.—*Elevation, showing Shafting.*

FIG. 7.—*Line Shafting on Ground Floor.*



The engine indicated 61·75 I.H.P. at the first trial, 141 I.H.P. at the second, and 210 I.H.P. at the third. From these powers it will be seen that the line shafting absorbs 29·3 per cent. of the total power, the countershafts and machines 67 per cent., and that only 33 per cent. is actually applied to the cutting tools.

Before instituting a comparison between the old and new systems of driving the works, it may be well to enumerate briefly the various units which made up the old installation. These were—

1st. A marine type boiler working at a pressure of 80 lbs. per square inch. The feed-water for the boiler was heated to 205° F. as in the new boiler.

2nd. Three compound non-condensing engines indicating collectively 151·2 I.H.P. for driving purposes.

3rd. One compound non-condensing engine for lighting purposes of 64·66 I.H.P. The boiler evaporated about 6·75 lbs. of water per lb. of coal, and the engines used 43·8 lbs. of water per I.H.P. per hour. This gave an average coal consumption of 6·4 lbs. of coal per I.H.P. per hour. In calculating the cost of a horse-power for a year, the coal used for raising steam for smithy hammers and blower engines has not been taken into account, but the steam for electric lighting has been charged in each case, as it was almost impossible to obtain accurate figures without doing so. The proportion of steam used for smithy hammers was found by working the smithy under normal conditions for three nights of 12 hours each. The blower engines were also run at their normal speed during this test. It will be seen that the power for electric lighting is much greater in the new than in the old system, and it may be contended that the greater efficiency of one horse-power in the new system of driving is partly due to the better lighted workshops, but this is a refinement into which the scope of this Paper does not permit of investigation.

It now remains to be shown by how much the new system is better than the old, or, in other words, at how much smaller cost it produces work. Since the power in an engine works is expended in removing material from rough castings and forgings, a figure may be found by which different systems may be compared; the system by which a given weight of material is removed at the smallest cost is the most efficient. In order to make the grounds of comparison similar, the cuttings produced by machines whose scrap is not in proportion to the power expended—such as shearing machines and band saws—are not taken into account, but the weight of all turnings, etc., for a fixed period is divided by the cost of one horse-power for the same period, and a money value for the power per ton removed can thus be obtained. From the following Tables 2 to 5 it will be seen that the cost of removing one ton under the old system of driving was £5·21 and under the new system £2·48, showing a saving by the new system of 52 per cent. Notwithstanding the saving, it is clear that when the surface condenser is fitted the cost of one I.H.P. will be much further reduced.

It is hoped that the figures given may help to provide a basis on which to calculate the relative efficiency of the driving plant in similar works.

Table 2.

Cost of one I.H.P. per year of 3,000 hours under Old System.

	£	*s.*	*d.*
Coal—1,545 tons at 11*s.* 6*d.* per ton	888	7	6
Wages for steam raising	176	2	0
,, ,, engine tending	194	1	0
Maintenance of engines and boilers	80	10	0
Oil waste and sundry stores	23	16	0
Water, 2,172,133 gallons at 30*s.* per 100,000 gallons	32	8	0
Cartage of ashes	11	11	0
Total	1,406	15	6

$$\frac{\pounds 1{,}406\ 15s.\ 6d.}{\text{Mean I.H.P. } 165{\cdot}2} = \pounds 8{\cdot}5 \text{ per I.H.P. per year.}$$

Table 3.

Cost of one I.H.P. per year of 3,000 hours under New System.

	£	s.	d.
Coal—1,360 tons at 11*s.* 6*d.* per ton	782	0	0
Wages for steam raising	92	0	0
„ „ engine tending	200	0	0
Maintenance of engine and boiler	25	0	0
Oil waste and sundries	28	10	0
Water 2,750,000 gallons at 30*s.* per 100,000 gallons	41	5	0
Cartage of ashes	10	4	0
	1,178	19	0

$$\frac{\text{£}1{,}178\ 19\ \ 0}{\text{Mean I.H.P. } 271{\cdot}3} = \text{£}4{\cdot}34 \text{ per I.H.P. per annum.}$$

Table 4.

Old System.

Material removed per annum	245 tons.
Material removed per I.H.P. per annum	1·61 „
Cost of removing 1 ton of material	£5·21

Table 5.

New System.

Material removed per annum	367 tons.
Material removed per I.H.P. per annum	1·74 „
Cost of removing 1 ton of material	£2·48

The Paper is illustrated by 7 Figs. in the letterpress.

Discussion.

The CHAIRMAN said the Paper gave in a very concise form the results of valuable practical experience, and he would ask them to pass a vote of thanks to the authors for putting it before them.

Mr. ALFRED SAXON had been interested in the Paper, because the firm with which he was connected had made a complete alteration to electric driving within the last two years. Could the authors give any idea of the cost of the installation, so that an opinion could be formed as to the gain from a monetary point of view arising from the alteration? Another question he would like to ask was—what was the friction of the engine? In one place (page 971) they stated that the line shafting absorbed 29·3 per cent. of the power developed. He should take it that the engine and the line shafting together absorbed 29·3 per cent. He had made many tests of engine and gearing friction, and he considered this example to be rather high. A noticeable feature in marine districts was that they did not seem to appreciate the value of fuel economisers. In this case they were told that a feed-water heater was applied, and the temperature of the feed-water entering the boiler was 205° F., that was 7° under boiling point. In Lancashire cotton-mill practice a feed-water temperature of 250° to 300° would be attained by utilizing the waste chimney-gases through an economiser, and he was sure much better results would follow. There was another point, and he thought it would minimise somewhat the further results the authors expected, namely, the feed-water heater would have to be dispensed with when the condenser was fitted, and then the feed-water would have to be supplied considerably under 205°. He was very much obliged to the authors for the Paper, and would attempt to institute comparisons with his own works' driving arrangements, and had no doubt other engineers would be wise in doing the same.

The CHAIRMAN asked Mr. Saxon if he got these results soon to kindly forward them to the Secretary to be included in the discussion.

Mr. W. H. Allen said he had carried out a good many experiments on this subject, and briefly, the following figures were the results of readings taken of the energy given out by the generator in an engineer's shop:—25 per cent. was taken in the shafting, 25 per cent. in the top gearing, while the tools themselves required 30 per cent. in the smaller ones, and 20 per cent. in the large tools, so that the average percentage of work done in actually cutting metal in an engineer's factory was not more than 25 per cent. While so many of them were anxious to endeavour to save a few per cent. at the engine, boiler, and dynamo end, they seemed to neglect the fact that 25 per cent. of the energy was involved in the type of overhead shafting, which was always offering a resistance to the generator, whether the machine be at work or not. This useless wastage could be readily dispensed with, and a great saving made in belting, gearing, noise, and economy in horse-power, by adopting the clutch system. Instead of top gear at the Queen's Engineering Works, Bedford, they employed a form of clutch direct on the cone, and this was a great improvement upon the old system of driving engineers' tools from shafting.

Mr. Bryan Donkin, Vice-Chairman, said it seemed to him that this was a very interesting series of experiments. If the boiler efficiency could be added to the results, it would increase their value.

Mr. E. R. Walker pointed out that the saving was probably due solely to the improved engine and boiler with its greatly increased pressure, and not to the application of any electric driving.

Mr. Crighton, in reply to Mr. Saxon, said they were unable at present to give the comparative cost of the old and new systems. In the matter of engine friction, they had taken indicator diagrams showing this, but had not embodied them in the Paper. They had made no experiments to find out the loss from the countershafts and top gearing independent of the main shaft. With reference to Mr. Donkin's query about the boiler efficiency, they had found it, as a

(Mr. Crighton.)

rule, to vary from 68 to 73 per cent., and as high as 78 per cent. had been attained.

Communication.

Mr. Alfred Saxon wrote, in continuation of his remarks at the Meeting, that he had had a number of calculations made and information extracted, but found himself unable to institute a comparison on the lines furnished by the authors.

PNEUMATIC RIVETING, AND OTHER USEFUL APPLICATIONS OF PNEUMATIC TOOLS.

By Mr. J. C. TAITE, *Member*, of London.

The author, having been asked to write a short Paper on Pneumatic Tools, and having regard to the comparatively recent one, read by Mr. E. C. Amos,* when a lengthy discussion followed, has confined these remarks principally to pneumatic riveting, with special regard to the pneumatic exhibits at the Glasgow Exhibition.

Shell Riveter.—With the introduction of the "Boyer" long-stroke hammer for shell riveting, rivets up to $1\frac{1}{2}$ inches can be successfully knocked down, and the pneumatic holder-up has overcome the difficulties of the old method. The length of this Paper does not allow of a full description of the appliance; the most noteworthy feature, however, is that the riveting hammer is mounted, and has a travel of $3\frac{7}{8}$ inches in an outer cylinder, to which air is admitted when the hammer trigger is depressed. The pressure acts on a collar surrounding the hammer barrel, and shoots the tool forward on to the rivet head, the notched bar at the other end of the rigging being adjusted to provide the reaction necessary for the snap to be continuously pressed on to the rivet, while the percussive riveting action is performed by the hammer. The hammer with its casing is mounted in a spherical bearing which enables it to be turned about through any desired angle within the requisite limits. Another and later development is the No. 9 long-stroke hammer, in which the trigger is dispensed with, and air is admitted by a throttle valve.

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* Proceedings 1900, page 119.

Riveter with tail piece.—Fig. 1, Plate 166, shows a riveting hammer with tail piece largely used in shipyards for beam knees; the length of the tail piece is suited to the spacing of the frames, so that when air is admitted the hammer jams itself between the rivet and the adjacent beam during the percussive riveting operation, the pneumatic holder-up exerting pressure in a similar manner on the rivet head from the other side.

Deck riveters.—These tools have been longer in use in the American yards than here, but they are now being gradually introduced on the Clyde. From the fact that a longer rivet is required than that used by hand it follows that the hole must be more thoroughly filled.

Bridge work.—For this description of work pneumatic tools, Figs. 2 and 3, Plate 166, are eminently adapted, inasmuch as a satisfactory plant for riveting *in situ*, easily moved from one place to another, has long been wanted. At the construction of the Godaveri Bridge at Rajahmundry, Fig. 8, Plate 168, Mr. T. F. G. Walton used pneumatic tools, and an extract from his Report is contained in Appendix I (page 980).

Mr. A. B. Manning (Missouri, Kansas and Texas Railway), in a report to the Committee of the Association of Railway Superintendents of Bridges and Buildings at the Annual Convention, St. Louis, 16th October, 1900, gives the following interesting figures comparing hand and pneumatic riveting:—

"Men with pneumatic riveter will average 500 rivets per day for 8·12 dollars = 33*s.* 3*d.*, or 1·62 dollars = 6*s.* 7*d.* per hundred.

"Men with hand power average 250 rivets per day for 9·20 dollars = 37*s.* 8*d.*, or 3·68 dollars = 15*s.* per hundred." (See Appendix I, page 981–2.)

In England the cost of $\frac{7}{8}$-inch rivets with pneumatic hammer is 4*s.* 6*d.* per 100, as against 10*s.* 6*d.* by hand. An ingenious arrangement for carrying a drill, used on the Great Eastern Railway, is shown in Fig. 6, Plate 167; and the same arrangement would be equally useful for drilling holes in the long girders of bridges which cannot be drilled under the ordinary machine.

Locomotive work.—One of the most recent developments in pneumatic tools is that shown on Fig. 7, Plate 168, with tube cutter. This tool is similar to the ordinary drill, but has in addition an air cylinder and piston which forces out a taper mandril, thus pressing the cutting edge of the tool against the tube. By the use of this tool $2\frac{3}{4}$-inch diameter steel tubes can be cut through in five seconds. The reversible drill with the ordinary tube expander is now also largely used for tube expanding. Pneumatic drills are employed for drilling out stay-bolts and re-tapping the holes, and give every satisfaction, a saving of £7 per boiler having been effected in the cost of re-staying the fire-boxes at one of the principal yards. Railway-wagon floors are riveted pneumatically, a saving of 15*s.* per wagon being effected. A report from the shops of one of the French railways states that 16-inch manhole doors are cut in the locomotive boilers in fifteen minutes, the plate being $\frac{7}{16}$-inch thick, and $1\frac{3}{4}$-inch tubes are rolled in twenty-seven seconds each.

General Boiler work.—The long-stroke hammer is used for riveting up the end circumferential seams of Lancashire, Cornish, and vertical boilers, air receivers and superheaters of water-tube boilers where the hydraulic riveter cannot be used, also on manhole rings, Galloway tubes, combustion chambers and rivets connecting furnace tubes to the front plate; and one firm is employing a gap riveter for the furnaces themselves. These are also used in making large tanks, Fig. 5, Plate 167.

With the extension of the use of pneumatic tools, the size of compressors employed has been materially increased, and many Works which have started with either a Westinghouse air-pump giving 40 cubic feet of air per minute, or an oscillating compressor giving 60 cubic feet per minute, have now compressors giving 300 to 350.

The fullest advantages in increased output and economy have not yet been reached in this country, owing to the Trades Unions not having, up to the present, allowed rates to be made sufficiently remunerative to the masters, but the enormous saving effected in other countries particularly by pneumatic riveting must soon have its effect in this country.

The Paper is illustrated by Plates 166 to 168.

APPENDIX I.

At the construction of the Godaveri Bridge at Rajahmundry, Fig. 8, Plate 168, Mr. T. F. G. Walton used pneumatic tools, and the following is an extract from his Report:—

"Riveting was done partly by hand and partly by "Boyer" pneumatic riveters. These machines did most excellent work, and on certain parts of the girders did the work much quicker and cheaper than could be done by hand. The riveting of the bottom booms and the diagonal and vertical joints in it could be almost entirely done by the machines; but there was difficulty in suspending them for working on the top boom, and as they could be kept continuously at work on the bottom booms alone they were shifted on from span to span as those booms were riveted up, and hand riveters got to work on the upper booms. For working these machines, the air was compressed to 100 lbs. pressure, and passed into a receiver. Four machines could be worked at one time from this receiver without reducing the pressure below 80 lbs., and on straightforward work from 900 to 1,000 1-inch rivets could be put in daily, and about 600 rivets when the machines have to be constantly shifted about for joints for diagonals and verticals. The cost of working them per day is 17 rupees, or reckoning 750 rivets as a day's work, the cost works out to 2·27 rupees per 100. This is not allowing anything for the heating fuel or prime cost of the pneumatic installation, but only the labour and the cost of running the compressors. As compared with this, hand riveting was paid for at an all round rate of 5 rupees per 100, 53½ per cent. being 1-inch rivets, 9½ per cent. ⅞-inch, and 37 per cent. ¾-inch, and therefore the rate for hand riveting 1-inch rivets may be put at 6 rupees per 100, without cost of fuel or tools, or nearly three times the cost of machine riveting. For hand riveting, contractors were allowed 1 lb. of coal per rivet. The loss of rivets amounted to 0·9 per cent. of the total issues. An excess of 10 per cent. on the net quantity of rivets was sent from England, and there is therefore a very large surplus of rivets and rivet rod, amounting in all to 69 tons. Very little riveting was done over water, and therefore the usual excuse of "lost in the river" for rivets and tools was not available, and I think with careful check on the issues that the loss has been kept as low as one can expect."

The following are extracts from the Report of the Committee of the Association of Railway Superintendents of Bridges and Buildings at the Annual Convention, St. Louis, 16th October 1900, and furnish some interesting figures for comparison.

Mr. A. B. Manning (Missouri, Kansas and Texas Railway), the Chairman of the Committee, reports:—

"With pneumatic riveting hammers I find two men and one heater can average daily (10 hours) 500 rivets, whereas by hand 250 rivets per day was a good day's work (more often less) for three men and one heater. One day we drove 700 rivets by using an additional man to take out fitting-up bolts, etc. This was the work of one air hammer only. In inspecting rivets I find the work far superior to hand work—less loose rivets, heads invariably perfect, shank of rivet filling hole, and in every way far superior to hand work done by our men or by others in the past; also work can be done readily in places where great difficulty has been experienced with hand tools. Men with pneumatic riveter will average 500 rivets per day for 8·12 dollars = 33*s.* 3·3*d.*, or 1·62 dollars = 6*s.* 7*d.* per hundred. Men with hand power average 250 rivets per day for 9·20 dollars = 37*s.* 8*d.*, or 3·68 dollars = 15*s.* per hundred. In putting in staging or falsework for riveters we find the cost is less, and by doing the work faster by air enables slow orders or delays to movement of trains to be reduced."

Mr. Edinger, of the Southern Pacific Company, Member of the Committee, reports:—

"Two men and a heater form a riveting gang, and they drive double the number of rivets per day than the gang of three men and a heater were driving by hand. With pneumatic tools a great many rivets can be readily driven in places which would be inaccessible to hand tools, from the fact that rivets can be driven where there is room to insert the hammer, which is about 20 inches long. The chipping hammer is frequently useful in trimming and capping, and with it all anchor bolt holes in masonry up to 1 inch in diameter are drilled by simply inserting a pointed drill and holding it up to the work. Larger holes are drilled with the heavier hammers. There is a saving of about 25 to 40 per cent. over the cost of hand work in drilling these holes. In fitting up the work ready for riveting a reamer is used in the drills, which one man readily handles, and which ensures a full bearing for the rivet, and does not burr and separate the plates as is the case where drift pins are used. This, while perhaps not reducing the cost very much, improves the character of the work. We also use the air drills for boring all bolt holes in bridge floor timbers by inserting an auger in place of the drill. This results in a saving over the cost of hand boring of about 50 per cent., which would be further increased, I think, by using the pneumatic boring machines, which run at higher speed and are more convenient to handle. The cost of fitting up and riveting on new steel bridges (all rivets $\frac{7}{8}$ inch) averages to date 35 per cent. less than if the work had been done by hand for all work done since we have had the pneumatic tools in use. Work now being done with pneumatic plant costs 40 per cent. less than on hand work, and we expect to still further increase this percentage as the men become more expert with the tools. The character of the work is much better than we have been able to do by hand. The amount of staging required from which to drive rivets with pneumatic tools is very much less than is required for hand riveting, as it is only necessary to provide seats or standing room for two men, for which, ofttimes, a single plank suffices. In riveting viaduct towers, laterals in spans, etc., where there are only a few rivets to be driven in a place, the saving on erection of staging alone is a very considerable item."

APPENDIX II.

Mr. A. Hamilton Church has drawn attention * to the policy of the British working man.

Mr. Church asks if there is no one to undertake a campaign to convert the British artizan to a proper appreciation of the true principles of progress? Millions are spent in the course of a few years in the strife of political parties to decide whether A. or B. shall occupy a certain office; but the far more vital question of bringing the interests of masters and men to one focus, uniting them in defence of their own industry, permeating them with a desire to increase the efficiency of their own powers, mental, physical and mechanical, so that they may keep to the front in spite of all opposition and competition, is wholly neglected.

As an example of the appreciation of pneumatic tools for shipbuilding in America, the following is a list of tools in use in Cramp's Yard at Philadelphia:—4 compressors, 43,500 feet of hose. Throughout the yard and aboard ships now at the yard there are 1,420 hose connections; there are 494 hose connections in addition. Pneumatic tools now on hand are:—236 drills, 75 shell riveters, 22 deck riveters, 41 jam riveters, 144 holders-on, 87 "Boyer" L. S. hammers, 173 "Boyer" No. 1 hammers, 110 chipping machines, 91 "Boyer" No. 2 hammers, and 39 "Boyer" No. 3 hammers.

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* Cassier's Magazine, March 1901.

For comparison of prices the following is valuable, as it shows the small cost of machine riveting :—

	Rivets.	Total cost.	Cost per rivet.
Machine Piece-work .	37,428	990·49 dollars	2·64 cents.
Hand „ „ .	56,797	2,672·72 „	4·71 „

From this it will be seen that the cost per machine rivet is but 50 per cent. of that of the hand driven rivet.

The above refers to battleship and ordinary merchant work. On the new American liners in the lower yard the prices are usually greater, as shown below, due to the heavier construction :—

Size of Rivet.	Location.	Hand. cents.	Machine. cents.
$\frac{7}{8}$-inch	Vertical keel	3	$2\frac{1}{4}$
$\frac{7}{8}$ „	W. T. Vertical keel (C.K.) . . .	6	4
1 „	Keel between blocks	12	7
1 „	Keel seam	8	5
1 „	Shell on bottom	5	$3\frac{1}{2}$
1 „	Shell side	5	$3\frac{3}{4}$
$\frac{7}{8}$ „	Frames on ground	3	$1\frac{1}{2}$
1 „	Inner bottom	5	$3\frac{1}{2}$
$\frac{7}{8}$ „	„ „	4	$2\frac{1}{2}$
$\frac{7}{8}$ „	Floors on ground	3	$2\frac{1}{4}$

The hand prices given are those which would have to be paid, but all riveting on these ships up to date has been done by machines.

At the Coltness Ironworks in Scotland, where they formerly employed about ninety men for dressing castings, they now have only twenty trimmers and twenty-three labourers, the latter working the tools and the former being gradually reduced as new hammers are introduced.

Discussion.

The CHAIRMAN said the Paper they had just heard dealt with a class of tools which had been extensively introduced, but which they were only beginning to really appreciate. He thought every one would agree with the final paragraph of Mr. Taite's Paper, and every one who had used the tools would, he was quite certain, extend that use. New applications were continually being devised, and he did not think it would be long before the author came before them with another Paper describing still more varied applications of the system. He asked them, before commencing the discussion, to pass a hearty vote of thanks to Mr. Taite.

Mr. T. HURRY RICHES said his company used a great many of these tools, not only the hammers, but the drills, with very good effect, and were extending the use of the tools. He thought that was the best character that he could give them. He would call attention to one little matter there. The author said that seven-eighths inch rivets were knocked down at 4*s.* 6*d.* per hundred as against 10*s.* 6*d.* by hand. He thought the latter price was too high. The author might add with advantage to his Paper what the length of the large rivet was which he spoke of knocking down, compared with an equal-sized rivet done by hydraulic pressure. The machines worked extremely well, and were most thoroughly satisfactory, but for the heavier rivets, unless the rivet was thoroughly well heated right down, and with the point somewhat cooled, there was certainly a strong tendency to expand the end of the rivet without thoroughly filling the hole. He did not himself see at all why the difficulty should not be got over, but he thought for these large rivets the probability was they wanted rather a heavier hammer. He did not think he need trouble them with further remarks, because he had on a previous occasion spoken upon this subject.*

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* Proceedings 1900, pages 153 and 176.

Mr. Bell said that, as regards the comparison of pneumatic tools with hydraulic tools in putting together a frame for rolling stock, taking an ordinary six-wheel carriage, where they had about 700 rivets to put in by the hydraulic system, they had to leave out 80 of them on account of the difficulty of getting them into the corners, whereas, with pneumatic tools, every single rivet could be put in, and that was an advantage which the author had not mentioned. There was one other point, that if they had to put in 80 or 90 odd rivets by hand they must have qualified men to do it, and if they could do it with the pneumatic tool, the same labour that they employed did for the lot. That was a matter which they had appreciated at their works very considerably—the saving of labour in taking the different materials to the machines. They could now take a long sole and work on it with pneumatic tools. Every hole could be made in these plates and every rivet put in, and they did not need to shift the frame till it went out on its wheels, and that was an advantage which could not be attained with hydraulic pressure.

Mr. Chester B. Albree said he had had some little experience with riveting hammers, and had found that it was more a question of velocity than of the weight of the hammer, because the strength of the blow increased much more with the velocity than it did with the weight, and the velocity was determined by either the high pressure or by the length of stroke. The pressure that one could use was limited; but if too high a pressure were used, the rebound of the hammer was so great that a man could not hold it, and therefore the only tool to use was the "long stroke" with a moderate pressure. As to the length of the rivets, his experience was that the power driven by hydraulic, or pneumatic, or other pressure, required a long stroke; the pneumatic tools were intermediate between the hand and the pressure.

Mr. Taite, in reply, said he was exceedingly obliged to them for the way in which they had received his communication, which could hardly be dignified by the name of a Paper. In reply to Mr. Riches's question as to the cost, namely, 10*s.* 6*d.*, of driving 100 rivets by hand, that was simply a figure which was given to him by a firm who had done the work at this price; and with regard to the length of the rivet, he thought that with 3-inch rivets they made them about 3–16ths inch longer than rivets for ordinary hand riveting. With regard to Mr. Albree's remarks, the vibration was completely overcome in riveting large rivets, as the hammer was held in a rigging with spherical bearing attachment. Referring to the remarks as to difficulty in closing large-sized rivets, to which attention was drawn, he thought that a little practice was worth a good deal of theory, for at their pavilion in the Exhibition Grounds they were driving 1¼-inch rivets; he ought to mention that all the experiments he had referred to could be seen either in their Riveting Pavilion or in the Exhibition, and he would be only too glad if members would see for themselves whether they were perfectly satisfactory or not.

Communications.

Mr. EWART C. AMOS wrote that the members who had perused the Paper which he read before the Institution of Mechanical Engineers in the early part of last year,* and to which the author referred in his Paper, would remember that he dealt with practically every type of machine then on the market; and it was to be regretted that Mr. Taite had not treated the subject more fully, bearing in mind its importance, and especially during such an occasion as the Engineering Congress in Glasgow. The title of his Paper was comprehensive, but was not carried out in the subject matter, since this was practically confined to a brief reference to certain "Boyer" machines, not a single other type being referred to, although in his opening paragraph he inferred that the pneumatic exhibits at the Glasgow Exhibition would be dealt with. The two Appendices, which were interesting,

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* Proceedings 1900, page 119.

(Mr. Ewart C. Amos.)

were by other authors, and exceeded in length the Paper itself. In dealing with a shell riveter, the author would lead members to suppose that the "Boyer" long-stroke hammer was the only hammer capable of dealing with heavy shell riveting, although visitors to the Exhibition would have noticed "Little Giant" hammers closing 1-inch rivets, these same hammers being also made to deal with 1½-inch rivets. Again, it was surely erroneous to state that the chief feature of the "Boyer" long-stroke hammer was its mounting. The author's remarks on the time saved by the use of pneumatic motors for tube expanding were very brief, although this, together with the similar operations of tapping and reaming, formed some of the most important applications of these machines, as much as £50 per boiler being saved on tube-expanding alone. The tube cutter required also a pneumatic motor to drive it. The author stated that pneumatic percussion riveters were being used on various types of boilers for riveting up seams that could not be reached by the hydraulic riveter. This would seem to infer that pneumatic riveting was inferior to hydraulic; and it would be interesting to know at what pressure these boilers were built to work, since considerable difference of opinion existed as to whether percussive riveting was suitable for high-pressure joints. Although he had had to criticise somewhat adversely, he fully agreed with the author that the great saving effected by the use of pneumatic tools would secure for them a largely increased application in the near future, but it would be difficult to say at present what particular machine was likely to effect the greatest saving.

Mr. TAITE, in reference to Mr. Amos's remarks, in which he regretted the subject had not been treated more fully, wrote that Mr. Amos seemed to have lost sight of the fact that the Paper was limited, by the rules laid down, to a thousand words; and as it was quite impossible to deal comprehensively in that space with all the pneumatic tools at the Glasgow Exhibition, it was natural that the author should refer more particularly to what he considered the best type of tools, especially those with which his name was identified. With regard to Mr. Amos's remark as to the mounting of the "Boyer" hammer, special attention was drawn to this only for the purpose of shell riveting.

Comparing hydraulic riveting with percussive riveting, the reason that reference was made to riveting up of seams that could not be reached by the hydraulic riveter, was explained by the fact that the percussive pneumatic riveter was being very generally used in shops that already had a hydraulic installation, but it was not intended in any way to infer that percussive pneumatic riveting was inferior to hydraulic riveting; and as hand riveting was still largely used, there was no reason to believe there could be any objection to percussive riveting by the pneumatic hammer in the hands of a competent operator. A large number of boilers were now being built at several works in this country, to work at a pressure of 150 lbs., and the riveting was being done satisfactorily with pneumatic tools working at a pressure of 100 lbs. Early in January 1902 would be launched a ship of 14,000 tons, in which there would be 670,000 rivets, all of which had been put in with pneumatic riveters, and the result of this would be interesting to users of pneumatic tools.

AGRICULTURAL MACHINERY IN THE CANADIAN PAVILION AT THE GLASGOW INTERNATIONAL EXHIBITION, 1901.

By Mr. G. HARWOOD FROST, of Smith's Falls,
Ontario, Canada.

Agriculture is the art of cultivating the ground and obtaining from it the products necessary for the support of animal life. It is the oldest occupation of which we have any record, being mentioned in the earliest parts of the Bible, where we are told of certain persons being tillers of the ground and others being shepherds. The herding of sheep was confined to the mountainous districts, where the natural growth of grass afforded plenty of pasturage, and tilling the soil was carried on in the well-watered valley districts, where the periodic overflowing of the rivers fertilized the land and forced an abundant crop with little manual labour, after the ground had been prepared for seed and the seed sown. Hence the processes of agriculture originally employed were extremely simple, being confined merely to preparing the ground without any effort to stimulate its productiveness, and the plough was practically the only implement in use. To-day, by the use of mechanical appliances, the farmer prepares vast areas of land in a short time, sows the seed, stimulates the growth of the grain, and forces the maximum yield that the land is capable of; he opens up to cultivation barren wastes and unbroken tracks covered with coarse prairie grass; and he harvests the crop with a rapidity undreamed of even fifty years ago.

The process of agriculture may be divided into its several classes as follows:—

1. Preparing the ground for the seed by means of ploughs and harrows.
2. Sowing the seed—broadcast seeders and drills.
3. Cultivation and care of the growing crop—cultivators of various kinds, horse hoes, weeders, thistle cutters, &c.
4. Harvesting the crop—mowers, tedders, rakes and loaders for hay, self-binding harvesters and reapers for grain.
5. Preparing the crop for use—threshers and other machines.

In the Canadian Pavilion at the Glasgow International Exhibition, Canadian implements for the first four purposes are represented by the products of six factories, namely, the Massey-Harris Co., Toronto, the Frost and Wood Co., Smith's Falls, the Noxon Co., Ingersoll, David Maxwell and Sons, St. Mary's, all of which manufacture a large variety of implements, and the Verity Plow Co., and the Cockshutt Plow Co., both of Brantford, which are devoted exclusively to the production of ploughs.

The earliest implements used by the settlers in Canada were imported from Great Britain, but as the almost illimitable area of arable land in Canada became opened up to settlement, the demand for implements soon induced their manufacture at home. The rapid development of the West rewarded these early manufacturers with success, and the capacity of their factories was constantly increased until to-day Canada is the largest producing British Colony and, next to the United States, the largest producer of farming machinery in the world.

Ploughs.—The first demand was, naturally, for ploughs for breaking the land. The plough is the oldest and simplest of agricultural implements, being represented amongst the hieroglyphics on the ancient tombs of Egypt, dating back more than 4000 years; and as early as the year 1000 B.C. the plough was described by one of the Greek historians as consisting of a beam, a share, and handles. To-day it consists essentially of the same parts. Until the past century it was made of wood and its form had not undergone many changes, but now it is safe to say that no other instrument for use in agriculture or for any other purpose can boast of so many varieties of shape and construction as the plough. Its forms are numbered by thousands, every country and almost every locality having its own models, and every condition of land being provided for. The varieties shown in the Exhibition are a selection of those made in Canada to suit the conditions of Great Britain, where the soil has been cultivated for generations, and is free from many of the obstructions met with in the barren and unbroken wildernesses of Western Canada. They are constructed on the straight-line principle and all local conditions have been met. A difference in the method of holding and turning the plough in this country, although very slight, has been provided for by the use of two adjustable supporting wheels attached to the beam and by an increase in the thickness of the heel of the landside, to prevent too rapid wear at this point. The mouldboards are made of soft centre or "syndicate" steel, which prevents brittleness, and permits of cleaning; the landsides and coulters are made of crucible steel, highly tempered; the beams are of wrought-iron and the handles of wood, making the plough much lighter than the English steel-handled ploughs, with, as has been proved by experience, equal strength, and greater ease of handling. The points are made of cast steel, chilled, and may be detached and replaced by new points as they wear.

Harrows.—After the ground has been broken and turned by the plough, it is pulverised and a level seed bed made by the use of a harrow. The harrow is also used to clean land that has been ploughed, by bringing weeds, etc., to the surface, and to cover the seed. Of the harrow, there are shown several varieties:—the spring-tooth, the spike-tooth, and the disc, each having its particular merits and uses. Harrows are usually made in sections, which may be coupled together to allow two, three, or more sections to be used at a time. The framework of the spring-tooth harrow is made of one continuous bar of steel running entirely around each section, across which are several angle-shaped steel bars, and to these are attached, in different ways by different makers, a series of highly tempered steel teeth, about $\frac{1}{4}$ inch thick. The teeth are curved in such a way that they dig into the ground, tearing the clods of earth and levelling the furrows. The spike-tooth harrow is made in much the same manner, with the exception that it has solid steel teeth, in the form of pointed spikes, about one inch square, instead of spring teeth. In both these harrows there is a heavy coiled spring attached to an adjusting bar, to allow the teeth to yield when in contact with an immovable obstruction, and also to give them a continuous vibration. By means of a lever operating the adjusting bar, the teeth may be set at various angles for working over different kinds of ground.

The disc harrow is an implement extensively used in America, but only recently introduced into Great Britain. It is different from the others, being composed of a series of concave discs of highly tempered steel which cut the ground instead of tearing it. It will pulverise and level soil that is too hard for any other kind of harrow to handle properly. The discs are arranged in two sections of six, seven, or eight discs, which revolve on hardened steel ball-bearings. The sections are adjustable to any angle; in some makes by one lever which compels both sections to work at the same angle, in others, by two levers which allow either section to be set at an independent angle. The former has an advantage in ease of operation on perfectly level ground, and the latter has this advantage on rough and hilly land, while working equally well on level land. The depth of cutting can be regulated by the angle at which the sections are set, and in turning corners or working on hillsides the draught on the horses can be regulated in the same way. The sections are also flexible to allow either end to rise and pass over an obstruction. The discs are provided with scrapers arranged in sections, for keeping them clean, the scrapers of each section being independently locked on or off and shifted with the section of discs to which they belong. Each scraper works on an independent spring, and always fits tightly against the disc. The principal uses of this implement are cutting turf, and pulverising and levelling the ground after ploughing, but it is equally well adapted for covering seed sown broadcast, and for breaking up stubble land, which cannot be done satisfactorily with a toothed harrow.

Another kind of harrow, but only adaptable for use in light soil, is the chain harrow, made of a series of steel links.

Seeders.—The ground, being broken and level, is ready for the reception of the seed. The earliest method of sowing was to carry the seed in a receptacle, scattering it broadcast by the hand, and some fell on good ground and yielded a crop, while some fell on bad ground and was lost. In our day, however, the chances of thus losing seed are reduced to a minimum by mechanical devices. For different purposes, seed is sown either broadcast, or in rows or drills. Machines for both methods are shown, Plate 169; the broadcast seeder by the Massey-Harris Co., and the drill by the Noxon Co. Such seeds as corn, peas, beans, barley and some others are, as a rule, sown in drills, while grass seed, clover, and sometimes corn, are sown broadcast, but it is found that seeds sown in drills, on account of the greater regularity of distribution and depth of deposit, yield a crop more economically than when sown broadcast. There are two varieties of drills—the hoe and the shoe. The seed is contained in a box, from which it passes to the ground through a series of tubes, at the bottom of which are the open hoes or shoes. The hoe-drill hoes a channel through the ground by means of diamond-shaped points, the seed passes into this channel and is covered by the earth falling back on it. The shoe-drill has a row of steel runners with V-shaped bottoms which are curved upward at the points in a form resembling a shoe. These sharp bottomed shoes cut furrows through the earth into which the seed passes, and short drag chains attached to the rear of the shoes throw a loose covering over it. Grass seed may be sown from the drills by replacing the hoes with "scatterers," which, instead of digging into the ground, scatter the seed broadcast over it. In the regular broadcast seeders, the tubes are dispensed with altogether, the seed falling from the box, and spring cultivator teeth are attached which throw the covering over it. The feed-wheel which carries the seed from the box to the tubes consists of a solid cut-away cylinder of about two inches in length, Fig. 1, Plate 169. This is turned by a gearing driven by the road wheels, so that when the machine is at rest, the feed is closed; it is also closed when the hoes or shoes are lifted from the ground, or there is a motion of backing the machine. On the rear of the seed-box there is an indicator showing how much seed of different kinds should be sown to the acre—grain seed being given in pecks and grass seed in pounds, Fig. 2. By moving the pointer on this indicator to the figure showing the quantity it is desired to sow to the acre, the feed-wheel is shifted, enlarging or diminishing the size of the opening in the measuring channel to allow just the amount desired to pass through. Besides this there is a dial which registers the number of acres sown. The hoes are held in position by springs which allow them to pass over obstructions freely, and quickly return to their working positions. They are locked securely to the frame by clamps, without the use of bolts or pins, so that they may be easily removed and replaced by cultivator teeth. The depth at which they deposit the seed and the angle at which they cut the ground is regulated in some by spring pressure, in others by a mechanism similar to the reversing link of a locomotive; and they may be lifted out of the ground either all together by a lever, or independently by chains. Another lever is provided for shifting the hoes to a double-line, or zigzag position, to permit clods to pass between when working on rough lumpy ground that has not been sufficiently broken up by the harrow.

Cultivators.—The third process of agriculture—the care of the growing crop—is an important one, but the implements used for it are of the simplest variety. The ground must be kept clear of weeds and thistles, and it must be loosened up, especially while the crops are young, after it has become caked either by rain or by sun. For these purposes various implements are used, such as horse-hoes, spring-tooth and rigid-tooth cultivators, weeders, hillers, etc., but all may be classed under the general head of Cultivators. The most extensively used, and the only variety shown in the Canadian Section, is the spring-tooth cultivator. The framework is of angle steel and strongly braced; the teeth, or tines, are S-shaped, and are made of spring steel, oil tempered; the points are of various shapes, and are reversible and interchangeable, permitting points for various purposes to be used on the same tines. The teeth are arranged in sections, similar to the sections of the harrows, which are supported by a shaft at the front, and the depth of cultivation is regulated by spring pressure on each of the sections. On the Massey-Harris cultivator this pressure is applied from the front, while on the Frost and Wood, the Noxon, and the Maxwell implements it is applied directly to the rear, above the teeth. One lever, assisted by a coiled spring, serves both to lift the teeth out of the ground and to force them in, according to the depth desired.

Most of the spring-tooth cultivators are arranged also for use as broadcast seeders, space being provided above the front of the sections for the seed-box.

Harvesting.—The process of harvesting the crop is the one that has brought out the greatest ingenuity of man in the development of farming machinery. Neither the preparing of a seed-bed, nor the sowing of the seed necessitated the application of machinery in the early days, and natural fertilisation saved further labour, but when the crop ripened, it had to be gathered before the weather ruined it, and prepared for use. This was done by means of sickles, threshing floors, flails, winnowing boards, and grinding mills, all of which are shown by paintings in the tombs of ancient Egypt. Egypt was one of the first countries in which agricultural practice was developed and animal power applied to the various processes. From Egypt the knowledge of agriculture spread to Greece, thence to Rome, and from Rome to the rest of Europe, and the first mechanical device for cutting grain by animal power was suggested by the Romans. Pliny describes a device in use by the Gauls, in the form of a cart with a comb-like bar in front, which stripped off the ears of wheat and delivered them into a box. After the lapse of eighteen centuries the principle of this machine has been re-invented, and is now in use in the headers which harvest the enormous crops of wheat of Canada and the United States, where only the grain is gathered, leaving the straw to be burned. The problem of developing the primitive sickle and scythe into the most useful and available machines for harvesting the grass and grain crop of the world has long engaged the attention of man, but it was not until comparatively recent times that the practical results showed any great efficiency. During the nineteenth century, however, the mower, the reaper, and the binder have come into existence, and have passed through many stages of shape and principles of construction and operation into their present state of perfection. These time and labour-saving machines are now deemed indispensable by all who raise hay and grain, and their production has alone rendered possible the opening up to settlement and agricultural development of the prairie districts of America, Australia, Russia, Siberia, South America, and Africa, in all of which parts Canadian-made harvesting machinery is now in every-day use.

Both mowers and binders are exhibited by the Massey-Harris Co., the Frost and Wood Co., the Noxon Co., and David Maxwell and Sons. While the principles of operation and the results obtained are the same in all, the mechanical methods of obtaining this result and the devices by which the different machines meet the varying conditions imposed upon them are different, and each firm claims superior advantages for its own construction, which it is not the purpose of this Paper to discuss.

For harvesting the hay crop, four machines are used. The grass is cut by the mower, turned for drying by the tedder, gathered by the rake, and loaded on the wagon by the loader. Rakes are shown by three firms, tedders by two, and the loaders by only one.

Mowers.—On the Mower, Plate 170, a solid and heavy tubular cast-iron frame is used, as this secures a more perfect and permanent alignment of the running gear and shafting than a steel frame, which must be built up of several pieces bolted together. The wheels are of cast-iron, 31 to 34 inches high, $3\frac{1}{2}$ to 4 inches wide, and are provided with horizontal and vertical lugs on the rims to ensure good driving contact with the ground. The wheels communicate their forward motion to the shaft and the main gear-wheel through a ratchet and spring pawls on the inside of the hubs of both wheels, Fig. 3, Plate 170. From the main gear-wheel the motion is communicated to the cross-shaft by various arrangements of spur and bevel wheels and pinions, giving a rapid motion to the crank-disc, and thence to the knife through the connecting-rod. The connecting-rod is long, and is in some machines made of wood, the variety used being well-seasoned second-growth hickory, and in others it is of wrought-iron or steel. It is attached to the knife-head and to the crank either by a ball and socket joint, Fig. 4, or by a hook and eye, Fig. 5. The speed given is in a ratio of from 55 to 62 vibrations of the knife to one revolution of the drive-wheels. A lower speed than this would not cut rapidly enough in heavy grass to prevent some of it blocking the action of the machine, and a higher speed would overheat the bearings. The cutting apparatus, consisting of the heavy steel cutter-bar, the fingers or guards, and the sectional knife, is attached to a hinged portion of the main frame, called the hanger, by large bearings, and is supported at each end by a shoe with either wheels or steel runners. It is made of different lengths to cut a swath of from $3\frac{1}{2}$ to 6 feet wide, and the width of tread between the drive-wheels is proportionately wide—from $3\frac{1}{2}$ to 5 feet—to give the machine stability. The knife is held tightly against the guard-plates by several clips, to make a close shear cut and to prevent short and soft grass from getting between the knife and the bar. After much use, the constant strain on the cutting apparatus has a tendency to make it sag backward and to throw the knife and the connecting-rod out of line, although every effort is made by the use of large and strong bearings to prevent its doing so, and if this were not remedied the knife would cut into the fingers and soon the entire apparatus would be ruined. A strong brace is therefore provided, connecting the hanger with the solid tubular part of the main frame, which can be adjusted to take up any wear, and keep the cutter-bar and the connecting-rod always in perfect alignment. The hanger connection must also allow the cutter-bar to accommodate itself automatically to the most uneven surface, so that it may float easily up and down over all irregularities of the ground without interfering with the action of the knife. Convenient to the operator on the seat there are several levers, Fig. 6, one for throwing the machine in and out of gear, one for tilting the cutter-bar to any angle to suit the nature of the ground or condition of crop, a foot lever for raising the bar from the ground, temporarily, while turning corners or passing an obstruction, leaving both hands free to handle the reins, and a hand lever for raising the bar higher and locking it in the raised position. A coiled spring assists the action of both of these raising levers. On the outer shoe of the cutter-bar is a track clearer, which deflects the grass sufficiently to leave a clear track for the horse nearest the standing crop on the succeeding round of the machine. It works against a pressure spring that allows it to give freely before all obstructions. The horses draw the machine from below the pole, the draught being applied directly to the hanger, and the weight of the pole is counterbalanced by the driver on the seat, thus relieving all weight from the horses' necks while drawing the machine.

Hay Tedder.—This implement is used for tossing and turning the grass for drying. It can turn as much grass in one day as ten people can by hand, and by its use a much better quality of hay is secured than by hand turning, for the reason that it permits the grass to be more quickly and uniformly dried, instead of being sun-scorched on the top by being left too long on the ground and imperfectly turned. It is strongly and lightly constructed and is drawn by one horse. The frame is of angle steel, well braced to give rigidity, the wheels are of channel steel and about four feet high. There are six four-pronged forks, mounted on a zigzag steel shaft at the rear of the machine, giving the forks three positions, and they are pivoted about one-third their length above this shaft. The shaft is operated directly from the centre by a chain, the power coming from the drive wheels through an internal spur gear near the centre of the main axle. By a lever the forks can be adjusted up and down while in motion, and the machine thrown in and out of gear. The forks are provided with springs which prevent breakage from striking obstructions.

Rake.—The horse rake is made to dump either automatically by means of a friction band or a spur wheel on the axle, thrown on by a foot lever, or by a hand lever assisted by a coiled spring. The teeth are made of a fine quality of crucible spring steel, tempered. By the use of this material the Canadian manufacturers can use light weight teeth of less than $\frac{1}{2}$-inch diameter, while on all English makes the teeth are very heavy, being made of wrought steel and not tempered, of various shaped section, and about one inch thick. When the teeth are raised, the gathered hay is forced out by a line of clearing rods. The wheels and axles are of steel. The rakes are made of varying width from 7 to 10 feet, and the teeth are from 3 to 4 inches apart.

Loader.—The hay loader, Fig. 7, Plate 171, is a comparatively recent machine, but its use is being greatly extended every year. Its advantages are many, the principal being, perhaps, that by its use, hay is often secured when ready for the stack, that might otherwise be ruined by the weather. When the hay has been turned and thoroughly dried, it must be collected without loss of time, and the farmer often works far into the night rather than take the chances of losing his crop before morning. Further, the loading of the hay on the wagon is the most laboursome part of haymaking. With the loader it is possible for three men to place a ton of hay on the wagon in five minutes, while it would require the same men fully fifteen minutes to do the work by hand. The machine is attached to the rear of the wagon and operated by the same team that draws the load, adding but slightly to the draught. The driving power comes from the wheels through a ratchet and pawl in the hubs, which may be thrown on and off at will. These drive a cylindrical cage revolving on the axle and carrying six rows of curved teeth which pick up the hay and deposit it on an elevating screen whose driving roller is the revolving cylinder. It is then carried to the top of the loader whence it falls on the wagon, where it is put in position by hand labour. The angle of elevation is automatically adjusted as the height of the load on the wagon increases. An upright frame supports several long wood slats which rest on the ascending hay to prevent its being carried away by wind or falling over the sides.

Grain Harvesting.—For harvesting grain only two operations are necessary—the cutting, and the tying of the bundles. There are two machines for cutting grain—the reaper and the self-binding harvester, or binder, as it is more generally called. The reaper simply cuts the grain, delivering it in gavels, which must afterwards be tied by hand. Of the reaper there are two varieties—the manual delivery and the automatic self-delivery. The binder both cuts the grain and ties it in sheaves. In the early days, when machines were first produced to take the labour of tying off the hands of the farmer, wire was used, but this had many disadvantages and gave much trouble to users. Experiment finally produced the twine-binding harvester of to-day, which ranks high, not only as a great time and labour-saving machine, but as one of the greatest inventions of the nineteenth century.

Binders, Figs. 8, 9 *and* 10, *Plate* 171.—This is essentially a place-changing machine; it cuts the grain, binds it in compact sheaves and delivers the sheaves, but it in no way alters the form or condition of the grain itself. To do this there are six distinct operations, namely, reeling, cutting, elevating, packing, tying, and discharging. The mechanism for each of the first four operations forms a complete machine in itself which can be worked independently, and those in which adjustment is necessary for varying conditions, are separately controlled by the operator, while the last two operations are worked together. The reel holds the grain against the knife until it is cut, then lays it on the moving platform canvas which carries it to the foot of the elevators. Here it is carried upward between two canvases to the top and on to the slanting binder-deck under which the packers work. It is then packed tightly against the binding cord until the required size of bundle is obtained, when a trip is pressed releasing a catch, which, in turn, throws the tying mechanism into gear. The needle arm rises through the deck, carrying the twine which completes the circle of the sheaf, a quick knot is tied, the twine cut, the needle quickly returns to its position below the deck, and the bundle is discharged on the ground or on a carrier at the will of the operator.

The entire mechanism is driven from a high and broad-rimmed steel wheel, whose motion is communicated to the main gear shaft through a large sprocket-wheel and a powerful endless chain, Fig. 8. On this shaft is located the clutch arrangement for throwing the machine in and out of gear, controlled by a lever within convenient reach of the driver when on his seat. From the main gear shaft the motion is communicated throughout the machine by means of chain and spur-wheel gearing. The main weight of the machine is supported by the driving-wheel, and the lesser weight by a steel grain-wheel at the outer end of the platform. At each end of the platform there is a divider extending about two feet in front of the knife. The outside divider separates the grain to be cut from the standing grain, supports it above the grain wheel, and lays it evenly on the platform. It is set at a slight outward angle to gather in a sufficient quantity beyond the end of the platform, to provide a clear track for the grain wheel.

The crank-shaft is driven directly from the main gear shaft by a bevel wheel and pinion. This drives the knife through a wooden connecting-rod as on the mower. At the rear end of the crank-shaft is the sprocket-wheel for driving the long main-chain which passes over several wheels, driving directly the platform canvas, the lower elevator canvas, and the packers, also a shaft or roller which drives the upper elevator canvas through a chain or wheel gearing at the front. This elevator must be driven from the front, as it is narrower than the lower to allow the heads of long grain to pass up clear of the canvases. The lower elevator is driven from its top roller, and this in turn drives, through two or three pinions, a free roller, inserted in the space between the top of the elevators and the binder-deck, to carry the grain across this space without danger of its falling through on to the main wheel. Each canvas is driven from one large roller, the other rollers being smaller and free running. The rollers are of wood with steel spindles inserted at the ends; they are pinned through in two or three places in different directions to avoid possibility of splitting, and they revolve in close-fitting cast-iron collars which prevent grain becoming twisted about the ends and blocking the action of the machine. The canvas aprons are provided with cross slats at intervals to hold the grain straight, and to prevent it from slipping.

A difference in the method of driving the upper elevator canvas in two of the machines may be explained here. In the Massey-Harris it is driven from the top, making the side next the grain the tight side, and in the Frost and Wood from the bottom, making this the loose side. At first sight this might appear to have different effects upon the grain, but the construction of other parts counterbalances this difference and makes the result the same. On the latter machine, Fig. 9, a third roller is introduced into the elevator to make the upper ply of the canvas run at an angle, leaving a considerable space between the two plies. The slope of the elevator not being very steep, a tight grip on the grain is not necessary in dealing with ordinary crops. The grain is carried up on the tight side of the lower elevator canvas, and is simply held in place by the loose ply of the upper canvas. But when the crop is extra heavy, the larger amount of grain deflects this loose ply upwards to get more space, thereby making the tighter grip that is necessary for the extra weight. On Fig. 10, on the other hand, the slope is steep and a tighter grip is necessary, which is obtained by driving the canvas so that the grain side is the tighter. To provide for extra heavy grain, the upper elevator is made to float, that is, the supports of the rear end are set in slots in a fixed frame, allowing the entire elevator to yield with the pressure of the larger quantity of grain. The purpose of these devices is to give the machines capacity for handling the heaviest crops without becoming choked.

From the front of one of the driving-rollers the reel is operated by a gearing so constructed that it allows great freedom of reel adjustment. On the Massey-Harris, the Noxon and the Maxwell binders this is accomplished by a bevel wheel and pinion, with bearings on the reel frame, the power being communicated from below through a square shaft which slides through the pinion as the reel is shifted. On the Frost and Wood the power is obtained from the top through a square shaft fitted with a sliding sleeve, and with universal joints at both ends, and the driving mechanism of the reel is operated through two chains, one for each of the two sections of the reel, which are independently adjustable. A rapid vibratory motion is also communicated through one of the rollers, to a butter, which evens the butts of the grain and brings it down on the binder deck to within reach of the packers. There are two or three rapidly and continuously moving packers which force the grain tightly against the twine and a compress hook, until the proper quantity for the size of bundle desired has been packed, when the pressure on a trip throws the binding mechanism in gear, it being driven from the packer shaft, generally by a chain, but in some by a bevel gearing, and in others by a combination of chain and spur gearing. All three of these methods are illustrated on the binders in the Canadian Exhibit.

Knotters.—These are different in detail in all the binders shown, Plate 172, but each consists essentially of a disc keyed to the knotter shaft working the movable parts either by cams or spur teeth, a notched disc or ring to hold the twine, a gripper or tying hook, a knife, and a stripping hook to remove the knot from the gripper when tied. One end of the twine is always held by the twine-holder tightly wedged between it and a short sleeve, and as the needle returns to its place, the twine is drawn through the eye from the twine can, being kept tight by means of a spring tension, and against this the grain is packed. When the knotting mechanism is set in operation the curved needle-arm rises, completing the circle around the bundle and carrying the twine beyond the holder, lays it across the top of the gripper and into one of the notches on the holder.

There are now two strands across the tying hook, which is given one quick revolution by the teeth on the disc, and in doing so a roller working along a cam has raised and closed the top of the gripper, tightly gripping the double strand and holding it while the twine is cut; and as the stripping hook removes the loop from the gripper, the ends are held and are drawn through the loop, thus completing the knot. The delivery arms attached to the revolving shaft now discharge the bundle, and the needle returns to its place. While the bundle is being bound and delivered, the grain brought up by the elevators is held back by the long curved needle-arm which prevents its becoming mixed with the knotter, and permits a clean separation of the bundles.

The bundles, or sheaves, may be delivered on the ground or on a sheaf carrier. The carrier is attached to the frame and is operated by a foot lever under control of the driver. It will carry as many as six sheaves, which are laid down at one place, thus saving much labour in gathering and stacking.

On all the binders, with the exception of the Frost and Wood, Fig. 13, the knotter driving-shaft is in the centre of the driving-wheel. On this, however, an eccentric lever wheel is used. When the bundle is being compressed and tied the chain draws on the long spokes, and when being delivered, it draws on the short spokes. The object of this arrangement is to obtain a greater power for compression, and for tying, thus making a more uniform draught by relieving the horses of the sudden and intermittent strains caused by the binding operation, and to give a quicker delivery of the bundle and return of the needle.

Adjustments.—A number of parts are capable of adjustment to meet the varying conditions of crops, land, and weather, nearly all the adjustments being made by levers within convenient reach of the operator, and while the machine is in motion. The reel has a wide range of adjustment up and down, forward and back, by means of a hand and a foot lever, to enable it to pick up long, short, or tangled grain, and lay it evenly against the knife and on the platform canvas. It is balanced by a spring, making it easy to operate, and permitting it to pass an obstruction without breakage. The tilt of the machine is regulated by another lever, to provide for cutting within an inch of the ground, which is necessary when the grain is much beaten down. To ensure the twine being tied about the centre of the bundle, whether the grain is long or short, the entire packing and binding mechanism may be shifted, the square packer-driving shaft sliding through the centre of the driving sprocket. Other adjustments, not made from the driver's seat, are: regulating the size of the bundle for damp or dry grain, which is done by altering the position of the compress hook; regulating the tightness of the twine about the sheaf; and raising and lowering the entire machine, by a crank and worm-gear working a spur pinion along an enclosed rack.

Local conditions are all provided for. The three conditions which are so different from those of Canada as to require special construction are, the value of the straw, the dampness of the climate, and the narrow gates in common use. The value of straw requires that the machine be made with an entirely open rear to allow any length of grain to be handled, while in America the rear of the machine is closed, and the height is regulated by the raise and lower gear to cut a length of straw that will easily pass up the elevators within the space between the closed ends. The Canadian climate is, as a rule, dry, but in Great Britain the grain is often so damp that it soon soaks the platform canvas, causing it to shrink, and when it dries again, the canvas expands. In order, therefore, to keep it always tight, springs are provided in the platform, which contract when the canvas shrinks and force the rollers outward again when it dries, thus keeping it always just tight enough to work perfectly. In Canada there are either no gates at all, or they are wide, but in Great Britain the gates are too narrow to allow the projecting points of the dividers to pass through easily when the machine is mounted sideways on the transport truck. To provide for this the dividers are made to fold, reducing the width of the machine by about two feet.

Bearings.—The application of roller and ball bearings to agricultural machinery, Plate 173, has resulted in so reducing the draught that two light horses can now easily draw machines formerly requiring three or four horses, and at the same time they have materially lengthened the life of the machines by reducing friction on the wearing parts. In all the Canadian mowers and binders shown in the exhibit, roller and ball bearings are used. The proper application of these bearings has been a problem that has taken years of experimenting to solve. At first they were used on the binder only for the bearings of the main driving-wheel, then they were put in a small grain-wheel and the main gear-shaft, and latterly they have been applied to the crank-shaft and to the bearings of the apron rollers. After a certain amount of experience, it has been found that on the crank-shaft they can be applied only at the gear end. At the connecting-rod end, the constant jarring caused by the rapid vibratory motion of the knife renders them impracticable, as the strongest cage is soon shaken to pieces, so at this place a renewable brass wearing bushing is used. Their use on the apron rollers has not proved a success, as the extremely small cages and rollers necessitated soon become clogged with oil and dust, so in a majority of the machines self-aligning metal bearings are used. The roller bearings are made of hardened steel rollers of $\frac{3}{8}$ to $\frac{5}{8}$-inch diameter, so set in a malleable iron cage that they are free to turn with little or no friction on the ends of the cage, and at the same time will not come out of place when the cage is removed for cleaning.

On the mower, rollers are used for the bearings of the drive-wheels and the intermediate gearing, and renewable brass bushings on the cross-shaft.

Ball bearings are used to take up the end thrust on shafts due to the bevel gear. On some of the machines provision is also made for taking up the wear in the bevel wheels, thus keeping them always in perfect mesh, and allowing the machine to work as evenly after years of use as when new.

Material.—The use of steel for the framework and platform of the binder is now universal. Formerly the platform was made of wood, some of the braces of wood, and some of iron, giving the machine a heavy and cumbersome appearance. With the reduced price of steel caused by the erection of a number of steel works in Canada, its use has been largely extended by all manufacturers. Now the platform is made of sheet steel rolled perfectly level, and braced beneath by diagonal and cross braces of angle steel. This gives the platform extra strength and rigidity combined with lightness. The main frame of the machine, the braces and shafting are all of steel; the sprocket wheels and the working parts on which there is not much strain are of malleable iron, and the bearings of the main gear-shaft are of cast iron, as is also the frame of the binding mechanism attachment, to keep the shafting in permanent alignment.

Reaper.—On farms where the crop is not of sufficient acreage to warrant the purchase of a binder, the reaper is used. The self-delivery reaper has a gearing driven from the main wheel, which operates four or five rake-arms over a quadrant-shaped platform. These lay the grain against the knife, carry it across the platform, and deliver it in even-sized gavels, ready for tying by hand. The adjustment of the rake-arms will allow every rake to deliver, as is done when the crop is heavy, or only the second, third, fourth or fifth, according to the crop, or all the rakes can be thrown out of gear.

The manual delivery reaper is a combination of the ordinary mower and a reaping attachment. This attachment consists of a tilting platform, pivoted to a cutter-bar, and the necessary guards, extension dividers, supporting wheels for the inside and outside shoes, and an extra seat for the second operator, who lays the grain against the knife by a long-handled rake, and drops the platform with his foot to allow the cut grain to pass off it.

In all varieties of farm machinery the manufacturer must have his machine:—Firstly, strong enough and of sufficient capacity to handle successfully the most difficult conditions to be met with in the class of work for which it is intended; Secondly, as light as possible without imparing its strength, and of the lightest possible draught; Thirdly, simple in construction and easy in operation. Agricultural implements are not, as a rule, operated by expert mechanical men, so there must be no complicated mechanisms, and all adjusting levers must be easily worked and convenient to the driver; Fourthly, reasonable in cost. Although the best material must be used in the construction, the fitting of the parts, the running of all gears, and the adjustments must be perfect, and the methods of construction must be of such a nature as to produce the machinery at a price within the reach of the farmers of all countries.

Canadian manufacturers have met these and other requisites by the use in their factories of the most ingenious labour-saving machinery, much of which is made for agricultural implement works alone, and by systems of shop practice that concentrate and specialise the different classes of work, with the result that they are able to place their goods on the markets of the world at a reasonable price, and with the certain knowledge that the machine in every part, as well as in its entirety, is perfect, that as soon as the several pieces, in which it is shipped from the factory, are put together, it will work, and successfully meet all reasonable conditions, and the many abuses, that are imposed upon it.

The Paper is illustrated by Plates 169 to 173.

Discussion.

The CHAIRMAN said it was a matter of regret that they had been compelled to ask Mr. Frost to read his Paper in such a condensed form. The class of machinery with which the author had dealt was one to which he himself happened to have paid, at different times, a good deal of attention. He could assure them it would repay any one to make a careful examination of the machines shown in the Canadian Section of the Glasgow Exhibition. An enormous amount of ingenuity had been displayed in the perfection of the various machines described in the Paper. They had been the outcome of a great deal of practical experience, and their present efficiency was the result of perseverance in the face of many difficulties. He thought that all these machines had been evolved by battling with serious practical difficulties that had arisen from time to time. He was sure that those members who took this Paper to the Exhibition and used it as a guide would derive great benefit from the examination of the exhibits. He asked them to accord a very hearty vote of thanks to Mr. Frost for the great care and trouble he had taken in preparing this Paper.

Mr. Frank S. Courtney, having had frequently to examine and test these machines in his capacity of consulting engineer to the Royal Agricultural Society of England, had the greatest pleasure in confirming the Chairman's remarks as to the high pitch of excellence to which these Canadian machines, more particularly their self-binding harvesters, ploughs, &c., had been brought, competing favourably in design and workmanship with the best productions of other countries.

Mr. Frost, in reply, thanked them for the reception given to his Paper, and trusted that anybody who was interested in it would visit the Canadian building in the Exhibition, and see the implements that they had there, which he thought would well repay a visit.

THE CASSEL SELF-REGULATING WATER WHEEL.

By Mr. E. C. de SEGUNDO, *Associate Member*, of London.

The rapidly-growing use of water motors for all industrial purposes renders any improvement in such machines of peculiar interest to engineers at the moment.

The scope for a good water motor is practically unlimited. A good water motor must combine efficiency with economy, be simple and reliable in its action, and capable of speed regulation within the limits of the best steam practice. The latter quality is the one direction in which hydraulic motors have made comparatively little progress hitherto. It is, of course, obvious that the control of a mass of moving water involves entirely different issues to those connected with the control of the flow of an elastic compressible fluid like steam. If the stop-valve of a steam engine be suddenly shut, the momentary increase of pressure in the boiler is inappreciable, owing to the compressibility, elasticity, and small specific weight of steam. The sudden stoppage of a mass of moving water is accompanied by diametrically opposite results, owing to the fact that water, in its physical characteristics, is practically the antithesis of steam, that is to say, it is practically incompressible, inelastic, and its inertia is considerable. The momentum of the water in a pipe line 1,000 feet long and 1 square foot in area, travelling at a speed of 6 feet per second, is roughly 12,000, and should the gate be closed in one second the resulting pressure at the lower end of the pipe line, due to the rapid reduction of velocity of the moving mass, would be 12,000 lbs., or roughly 80 lbs. per square inch. This, of course, would be in addition to the pressure due to the head under which the water was flowing, and which might easily attain very large proportions. It is significant that the existing literature upon the subject of water power treats the subject in a very guarded manner. Mr. Replogle, an acknowledged authority on the subject, and the inventor of a most ingenious and widely-used water governor called after his name, has made the following statement* :—

"The science of water-power governing has not yet reached so great a degree of perfection as the governing of steam-engines, yet the underlying principles are being studied by engineers, and the time is not far distant when water powers will be better constructed and governed as reliably and successfully as steam-engines, but that time will not come until the same principles are recognised in the former as in the latter."

In another Paper on the subject read before the American Institute of Electrical Engineers, the author, Mr. Garrett, said :—

"It is, of course, desirable to keep the pressure constant on the wheel, but in practice this is found to be impossible. Water-power governing involves a number of more difficult problems than those which appear in steam-engine governing."

Similar expressions of opinion could be cited from numerous other authorities on the subject, but it is unnecessary to multiply instances. The fundamental error, which has been made in the past, in endeavouring to solve the problem of governing water motors, is that attempts have been made to effect the desired result by analogous means to those adopted in steam-engine practice, that is to say, it has been sought to control the speed by controlling the volume of working fluid admitted to the motor. All such devices, however ingenious, have invariably failed to give satisfaction, and it has apparently only recently been recognised that the physical attributes of water cannot be ignored in working out the solution of the problem One method which has been attempted is by the introduction of relief valves, which are intended to open immediately the pressure due to the reduction of the velocity of flow by closing the valve when it exceeds a safe limit. The general consensus of opinion among hydraulic engineers, however, is that in practice relief valves do not bear out the promises of theory. Another method of relieving the pipe line from shock is to insert at a convenient point a vertical pipe of the same height as the head under which the turbine or water motor is working. The checking of the flow of water through the water motor results in an overflow from the top of the stand pipe, giving a measure of relief to the pipe line. It will be noticed that in each of these cases a certain waste of water is unavoidable. Unless the standpipe is of such a height as to admit of the water overflowing it is obvious that no useful purpose would be thereby served, as if the standpipe is made higher than the head of water with a view to economy, the water would simply rise in the standpipe to the height corresponding to the increased pressure of shutting off water, and the shock to the pipe line would be exactly the same. A practical method has been for some time in use in connection with high-head water motors of the Pelton type. It consists in mounting the nozzle in such a way that, upon the load being reduced, the nozzle can be deflected away from the bucket, thus reducing, to whatever extent necessary, the impulsive effect of the jet upon the buckets. Many efforts have been made to do this by means of governors based upon centrifugal action, but those who have experience of the extremely unyielding character of a jet of water under high pressure will at once recognise that any attempt to deflect a nozzle by a centrifugal governor is foredoomed to failure, because it would be almost impossible to design a centrifugal governor sufficiently sensitive and yet sufficiently powerful. As a matter of fact, it is common experience to find that the governors supplied with such deflecting nozzles have been disconnected, and some contrivance resorted to whereby the nozzle could be deflected by hand power. Nevertheless, the key note to the solution of the problem was struck when the idea entered the head of the first man who conceived the deflecting nozzle. Satisfactory water-power governing can only be established in two operations.

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* Journal of Franklin Institute, February 1898, page 99.

1st. The speed of the water motor must be controlled without regard to the question of saving water.

2nd. The apparatus for reducing the velocity of flow must then be brought into action.

Obviously these two operations may be commenced at one and the same time by suitable mechanism operated when a change of speed occurs, but separate mechanism must be employed for each, because the first must be effected as fast as possible; the second, however, can only be carried out at a speed which does not involve risk of a dangerous shock to the pipe line. This solution is the one worked out by Mr. Elmer F. Cassel, of Seattle, U.S.A., and is known as the Cassel system, Plates 174–5. Wherever the supply of water is so much in excess of the amount necessary to produce the requisite power, which is often the case, it is of course unnecessary to go beyond the first operation. The expense of a water-saving device would be money thrown away, because, when the water was not running through the motor, it would be running over the penstock.

Plate 174 represents a wheel of the vertical re-action type, which is built upon Mr. Cassel's system for speed regulation. Plate 175 shows one application of the many modifications of Mr. Cassel's inventions.

The wheel consists in principle of two discs or sections carrying upon their peripheries an equal number of buckets at the same pitch. These discs are free to slide upon the shaft, and bear upon a projection from an arm keyed to the shaft, whereby the impulsive effort of the jet upon the buckets is transmitted to the shaft. In this particular type of wheel, rollers are introduced at the various bearing points with a view to diminish friction. Upon each of the arms, which are keyed to the shaft, a double "T" lever is pivoted as shown, one end of the head of the "T" bearing against each of the discs. At the free end of the "T" lever a weight is fixed, which bears some definite proportion to the tension of the springs holding the two discs together. When the wheel is at rest, or running at full load under normal speed, the discs are kept close together in obedience to the action of the spring, the buckets being then close together and forming practically one bucket with a dividing rib down the centre, a form which has been much used in wheels of the Pelton, and similar types. The nozzle is so placed that the jet impinges centrally upon this rib. The action of the governing mechanism is as follows:—

The weights, at the free end of the "T" levers, are so proportioned that, at a normal speed of the wheel, the centrifugal force exerted by them will bring a pressure to bear upon the discs which is exactly equal to the tension of the spring holding the discs together. Should any portion of the load be thrown off, the tendency of the wheel is of course to increase in speed; this, however, also increases the centrifugal effort exerted by the weights, and the tendency to separate the discs becoming therefore greater than the tension of the spring holding them together, the discs, which are free, slide along the shaft, move away from each other, thus forming a gap between the buckets through which a portion of the jet passes without exerting any impulsive force on the wheel. The relative position of the buckets with regard to the jet is therefore determined by the load; provided always, of course, that this load is not in excess of the mechanical equivalent of the water delivered by the nozzle. At every change of load between the maximum load for which the wheel is built, downwards, the buckets automatically take up a position relatively to the jet, whereby only so much of the jet is utilised as is necessary to keep the wheel revolving at normal speed. The volume of water in the jet is then adjusted, and the buckets close up again at normal speed under the new load. The author has made a number of experiments extending over two months upon the speed regulation of a Cassel wheel 18 inches in diameter. During this period a variety of springs and sizes of weight were tried, and it was found that no difficulty was experienced in reducing the variation of speed to under 2 per cent. from normal, when the whole load was thrown suddenly on or off. Moreover, the variation was practically momentary, normal speed being again registered by the tachometer within three or four seconds after the change in load had been effected. The results of a trial, recently made by the author, of an 18-inch Cassel wheel driving a 5-H.P. dynamo, are worth recording. The dynamo was driven by a belt from the wheel, the wheel being connected to the mains of the London Hydraulic Power Company, the available head (owing to friction in the small hydraulic main) being about 670 feet. The electrical energy generated by the dynamo was taken up by a bank of 32 candle-power 200-volt incandescent electric lamps, so arranged that the load could be varied in five equal steps of 20 per cent., or could be thrown on or off suddenly. Successive variations of 20 per cent. in the load from full load to no load, and *vice versâ*, did not produce any appreciable variation in the speed, which was recorded by one of Elliott Brothers' continuous-reading speed indicators. When the whole load (4·6 horse-power) was thrown on or off suddenly, a variation of 1·7 per cent. to 1·8 per cent. from normal was perceptible on the speed indicator, but in less than three seconds the speed had returned to normal, so that the variation may justly be said to have been practically momentary. There was no fly-wheel on the water-motor shaft, or any other wheel except the 6-inch pulley for driving the dynamo. The author also made a number of experiments upon the change of variations of head upon the speed-regulating mechanism, and it was found that, when the head was varied suddenly from about 150 feet to over 1,000 feet (or rather more than 600 per cent.), the variation in speed was well within the limits quoted above, namely, it did not exceed a momentary variation of 1·8 per cent. from normal. When the changes of head were effected slowly, there was absolutely no speed variation that could be recorded by the speed indicator. It will be seen that this method of construction lends itself to all the best known types of vertical impulse wheels, and that, as the form of the bucket does not enter into the design of the speed-regulating mechanism, the efficiency of a high-head water wheel constructed on the Cassel system should be just as high as any other.

By means of a water governing device which could be of an extremely simple character, as it is not required to work very rapidly, the Cassel wheel can be arranged always to run with closed buckets at normal speed at any load below the maximum for which the particular wheel in question is designed. In these circumstances the buckets would only remain open during the period required for the adjustment of the flow of water to the new load by the governing device. Thus the combination of efficient speed regulation, and saving in water used, is effected, which certainly gives this form of water wheel a very great advantage over other types, in that the water is used to the best possible advantage, and the speed of the wheel can be relied upon to remain constant, irrespective of any variations in head or load.

The Paper is illustrated by Plates 174 and 175.

Discussion.

The Chairman said he thought that the applause, with which the Paper had been greeted, showed that it was hardly necessary to propose a formal vote of thanks to Mr. Segundo.

Professor Archibald Barr was very pleased to say a few words upon this interesting device. There were many cases where the saving of water had nothing whatever to do with the problem in hand, the requirement being simply to govern the speed of the motor. He believed, with all due deference to their American friends, that the name Pelton which was usually applied to this type of jet wheel was a misnomer. This type of wheel had been used before Mr. Pelton brought it forward as a commercial article. He believed that it would be used a great deal more in the future than it had been up to the present. It was the simplest form of wheel, compared well in economy with the best turbines when working at full power, and was much cheaper and handier in many ways. A great many people had tried to govern wheels of this type mostly by closing up the orifice by means of a plug worked by a relay governor. He did not like to speak of any work that he had been doing till it was more or less finished, but he might say that he had been working on this problem, and had suggested a very different mode of governing from that in the Paper. He took out a patent for an adjusting nozzle, and found that Mr. Wilson, of Belfast, had patented about the same

(Professor Archibald Barr.)

thing a week or two later. He had a case surrounding the nozzle proper which was made of india-rubber. By admitting more or less water pressure into the space around the india-rubber nozzle, he could constrict it and still retain the circular form within a large range of size. All the governor had to do was to control the pressure of water around the nozzle. At the request of Mr. Gilkes, of Kendal, he had made one of these nozzles, but unfortunately the only fall available was one of 500 feet, and the pressure was much too high to work with an india-rubber nozzle. The result was that the nozzle burst. He had not had time to make any further experiments, but hoped soon to do so. He did not propose his nozzle for use with high heads, but believed it could be made to work well at low and moderate pressure.

Professor JOHN GOODMAN thought that only those who had worked at the problem of governing water motors had any idea of the real difficulties involved. Even the Niagara turbines, which were designed by a commission consisting of the first engineers of the world, governed very badly indeed. With all due respect to the very ingenious contracting nozzle invented and just described by Professor Barr, he did not think that it would be a success alone and unaided, but if it could be combined with Mr. Cassel's motor, he thought that a practically perfect arrangement would result. He had been engaged for two or three years on experiments of a similar character, and had he thought found out exactly why a mere throttling device or a contracting nozzle could not be successfully used for governing a water motor. The Cassel motor was the best self-regulating machine he had seen; it was not perfect, but could not be in better hands than in those of Mr. Segundo.

Mr. BRYAN DONKIN, Vice-Chairman, wished to know the efficiency of this wheel, or the ratio of the foot-lbs. in the entering water to the effective work given out; also the best form of nozzle. There had been many experiments with small nozzles with steam and with high velocities, and a few with water.

Mr. Segundo desired to express his great appreciation of the manner in which they had received the Paper, and of the interesting discussion that had followed upon it. Professor Barr had referred to an india-rubber nozzle as a possible solution of the speed regulation problem, and had suggested that the form of nozzle shown in the diagrams might possibly not be the best one. That was a subject he would like to speak on at length, but at this advanced hour he must not say more than that Professor Barr's remarks on this important subject were most interesting and highly suggestive. At the risk of offending the susceptibilities of their American friends, he must admit that there was no doubt that the type of motor which went by the name of the Pelton wheel was used years before Pelton took it up. Professor Goodman had referred to the Niagara plant, and to the unsatisfactory working of the speed governing arrangements when he was there two years ago. He might mention that he had seen autographic diagrams which went to show that the recently introduced speed regulating gear was more successful. He had not had an opportunity of examining this autographic apparatus, nor the way in which the experiments were carried out, and they must not take what he said about that as a responsible statement. Professor Goodman's remarks were very interesting, and they would all look forward with great pleasure to hear what he had to say in detail in the Paper which he had promised to submit to the Institution. Mr. Bryan Donkin had asked about the efficiency of the Pelton wheel. He had heard 92 per cent. claimed for it, but he had never managed to get a higher efficiency than 75 per cent. He saw no reason why the Cassel wheel should not attain that efficiency in practice. It must be remembered, however, that in practice accurate speed regulation was in many cases much more important than economy of water. He hoped before long to be in a position to make an extended series of experiments upon the economy of this wheel under varying conditions.

Professor Goodman said he was frequently testing the Pelton wheel, and obtained 80 and 82 per cent.

Mr. **Segundo**, continuing, said the question of the best form of nozzle had been raised by Professor Barr and by Mr. Donkin. Upon this important subject he had hoped to hear something from M. Rateau, who had made a special study of nozzles. Unfortunately the lateness of the hour had prevented his remaining to speak. He thought he had touched upon the chief points alluded to in the discussion, and could only again thank them for the favourable reception they had accorded his short Paper.

Communication.

Mr. **Murray Morrison** wrote that the speed regulation of the Cassel wheel, as described by Mr. Segundo, was certainly an ingenious and apparently effective one, which had the possibilities of simple application in practice. Those who had had experience in the regulation of water wheels were aware of the enormous difficulties of the problem, and this being so, any possible solution was of the highest interest. Where a turbine was required to run at a practically constant load, there would seem to be little doubt that the Cassel wheel, without the addition of any subsidiary water-regulating device, offered decided advantages over any other wheel at present on the market. In this country there were few cases of water-power installations where the supply of water was so abundant that a wastage was of no moment, or where the necessity of increased first cost in order to attain that end, by expenditure on enlarging catchment area or impounding works, was unnecessary; consequently, in the majority of cases, where the load was variable, a subsidiary water-saving device would have to be used in connection with the Cassel wheel. The saving of shock to the pipe-line, otherwise obtained, would then be to a certain extent lost, but the accurate speed regulation, in general cases the most important factor, would be retained. The addition of such devices did not necessarily complicate matters, and the efficiency thus obtained under varying loads ought to be practically the same as in ordinary governed turbines of similar construction, without the Cassel arrangement.

The wheels mentioned in the Paper were of very small size, and the above remarks referred only to them. It would be interesting to know whether larger ones had yet been tried, and to what extent they were satisfactory with regard to quickness and closeness of regulation. It was very important to be able to couple electrical machinery of standard design direct to turbines, and in the case of turbines working under a high head, it must be remembered that a limiting factor for the speed of the set was the peripheral speed of the commutator in the case of continuous current machines, and frequency in the case of alternators; it therefore often became necessary, in order to keep the speed within workable limits, to increase the size of the turbine beyond that actually necessary to develop the required power. Under these conditions the moving parts of the wheel, controlled by the governor, had a considerable inertia and friction, and one would expect the turbine to take an appreciably greater time than the smaller ones to resume normal speed. It is also questionable whether the mechanical construction of wheels of large size would not give trouble.

Mr. Segundo wrote that, with reference to Mr. Murray Morrison's remarks, it would appear that he held the view that the Cassel system had as yet not been tried on wheels of any but a very small size. Since reading his Paper at the Congress, the author had heard that the company developing the system in America had secured a contract for a large hydro-electric plant to consist of electrical units of 2,400 kilowatts, operated by Cassel constant speed wheels at a head of 2,600 feet. This at all events disposed of the suggestion, that any lack of confidence in the operation of this mechanism existed in the minds of those dealing with this matter in the home of its invention. Moreover, experiments that the author had carried out since the Congress had determined the fact that the centrifugal weights bore a fixed proportion of the

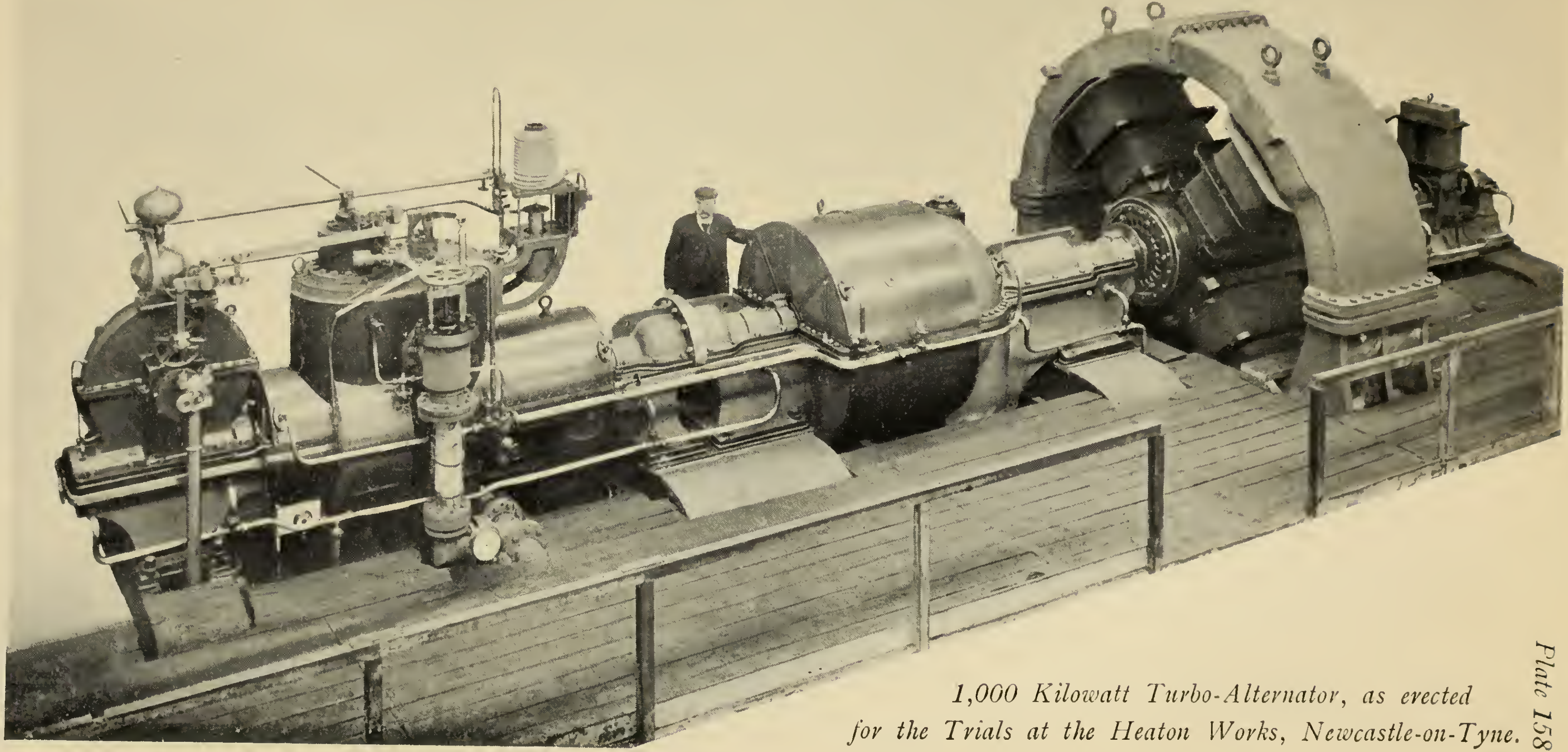
(Mr. Segundo.)

weight of the bucket-carrying disc, and that this proportion was apparently undisturbed by the size of the wheel.

He did not anticipate any difficulty in obtaining as close a regulation in the larger sizes, as he had already obtained in the wheel which was exhibited at the Engineering Congress, namely a speed variation of under 2 per cent. when the load was thrown on or off suddenly. The period of speed disturbance moreover was less than three seconds.

Note.—For further information about Tangential Water-Wheels, see a Paper by W. A. Doble, read at the California Meeting of the American Institute of Mining Engineers, in September 1899. [Secretary, I. Mech. E.]

The Chairman said before they parted that day he had to ask them to pass a vote of thanks to the Glasgow University Students' Union for the use of that Hall for their Meetings. It had been a very convenient hall, and he was sure that they felt greatly indebted to the students for its use. He asked them to pass that vote by acclamation. He also thought they would not like to part without expressing their congratulations to all who had had the management of the Congress for the excellent arrangements they had made. He congratulated the authorities most heartily on the great success with which these arrangements had been attended. The Congress had been a most thorough success, and their Glasgow friends were entitled to all the praise they could give them for the excellent manner in which they had carried out everything in connection with it.



1,000 Kilowatt Turbo-Alternator, as erected for the Trials at the Heaton Works, Newcastle-on-Tyne.

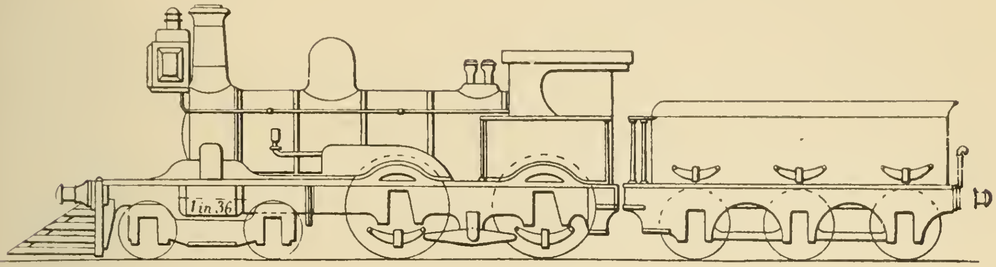
Plate 158.

COMPOUND LOCOMOTIVES IN SOUTH AMERICA. *Plate 159.*

Fig. 1. *Class 6.*

Cyls. 16 *in.* × 24 *in.*
Wheels, 5 *ft.* 8 *in.*
183 *Tubes,* 1⅞ *in.* (*outs*).

Heating Surface of Tubes ... 929 *sq. ft.*
" " *Firebox* ... 86 "
TOTAL ... ... 1,015 "
Grate area ... 16·5 "



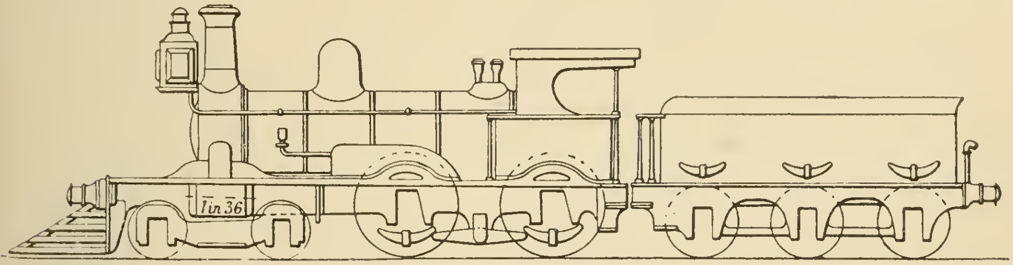
	T.	C.	T.	C.	T.	C.	T.	C.	T.	C.	T.	C.
Weight Working	16	0	11	6	11	4	8	10	8	9	8	6
" *Light*	14	8	10	11	10	1	4	2	5	19	3	5

Total Working 63 15·5 *Total Light* 48 7 *Water cap.,* 2,000 *gals.* *Coal,* 60 *cwts.*

Fig. 2. *Class 6A.*

Cyls. $\left\{\begin{array}{l}\text{H.P. } 16 \textit{ in.}\\ \text{L.P. } 23\tfrac{3}{4} \textit{ in.}\end{array}\right\}$ × 24 *in.*
Wheels, 5 *ft.* 8 *in.*
183 *Tubes,* 1⅞ *in.* (*outs*).

Heating Surface of Tubes ... 929 *sq. ft.*
" " *Firebox* ... 86 "
TOTAL ... ... 1,015 "
Grate area ... 16·5 "



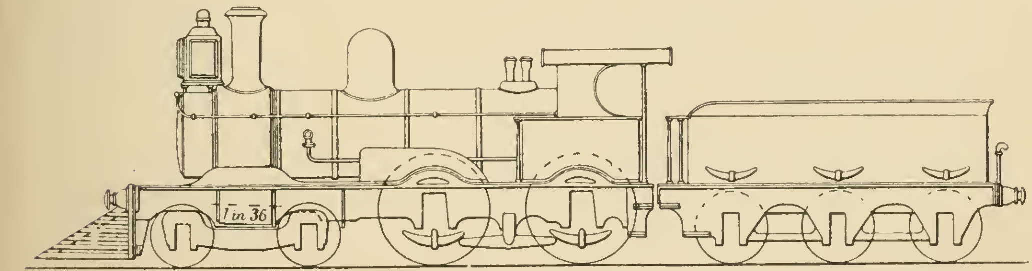
	T.	C.	T.	C.	T.	C.	T.	C.	T.	C.	T.	C.
Weight Working	17	0	11	16	11	14	8	10	8	9	8	6
" *Light*	14	14	10	15	10	6	3	19	4	4	4	15

Total Working 65 16·5 *Total Light* 48 15 *Water cap.,* 2,000 *gals.* *Coal,* 60 *cwts.*

Fig. 3. *Class 6B.*

Cyls. $\left\{\begin{array}{l}\text{H.P. } 17 \textit{ in.}\\ \text{L.P. } 24\tfrac{1}{2} \textit{ in.}\end{array}\right\}$ × 24 *in.*
Wheels, 5 *ft.* 8 *in.*
196 *Tubes,* 1⅞ *in.* (*outs*).

Heating Surface of Tubes ... 989 *sq. ft.*
" " *Firebox* ... 93 "
TOTAL ... ... 1,082 "
Grate area ... 17·5 "



	T.	C.	T.	C.	T.	C.	T.	C.	T.	C.	T.	C.
Weight Working	17	10	12	5	11	15	8	10	8	9	8	6
" *Light*	16	17	10	18	10	6	4	14	4	4	4	2

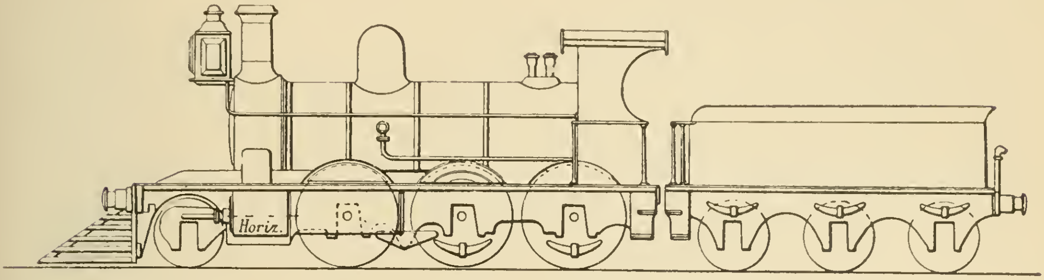
Total Working 66 15·5 *Total Light* 51 3·75 *Water cap.,* 2,000 *gals.* *Coal,* 60 *cwts.*

COMPOUND LOCOMOTIVES IN SOUTH AMERICA. *Plate 160.*

Fig. 4. *Class 7.*

Cyls. 17 *in.* × 24 *in.*
Wheels, 5 *ft.* 2 *in.*
185 *Tubes*, $1\frac{7}{8}$ *in.* (*outs*).

Heating Surface of Tubes ...	1,000 *sq. ft*	
" *Firebox* ...	86	"
TOTAL	1,086	"
Grate area ...	20·13	"



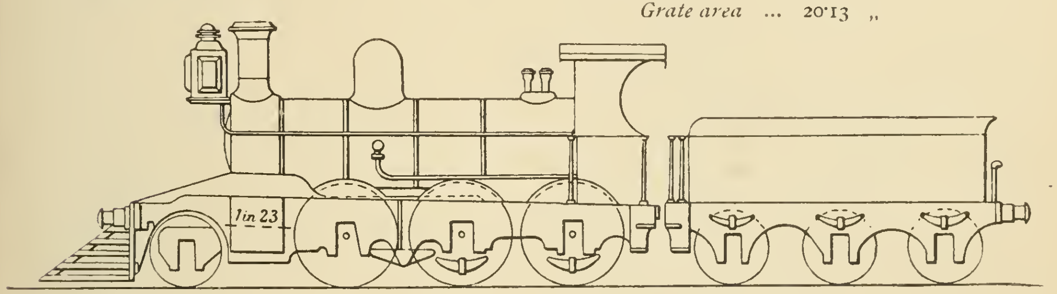
	T.	C.	T.	C.	T.	C.	T.	C.	T.	C.	T.	C.	T.	C.
Weight Working	9	3	10	15	11	6	11	3	9	13	9	12	9	9
" *Light*	10	4	7	17	8	9	12	2	4	17	5	2	4	10

Total Working 71 1·75 *Total Light* 53 1·5 *Water cap.*, 2,500 *gals.* *Coal*, 75 *cwts.*

Fig. 5. *Class 7A.*

Cyls. {H.P. 17 *in.* / L.P. $24\frac{1}{2}$ *in.*} × 24 *in.*
Wheels, 5 *ft.* 2 *in.*
185 *Tubes*, $1\frac{7}{8}$ *in.* (*outs*).

Heating Surface of Tubes ...	1,000 *sq. ft.*	
" " *Firebox* ...	86	"
TOTAL	1,086	"
Grate area ...	20·13	"



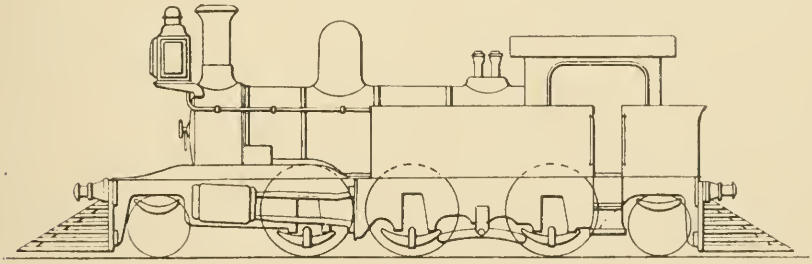
	T.	C.	T.	C.	T.	C.	T.	C.	T.	C.	T.	C.	T.	C.
Weight Working	9	6	11	1	11	5	11	14	9	13	9	12	9	9
" *Light*	8	17	9	11	10	12	10	14	5	1	4	11	4	11

Total Working 72 0·25 *Total Light* 53 19·5 *Water cap.*, 2,500 *gals.* *Coal*, 75 *cwts.*

Fig. 6. *Class 8.*

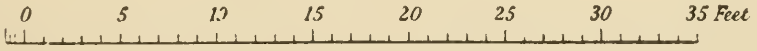
Cyls 16 *in.* × 24 *in.*
Wheels, 4 *ft.* $7\frac{1}{2}$ *in.*
187 *Tubes*, $1\frac{7}{8}$ *in.* (*outs*).

Heating Surface of Tubes ...	951 *sq. ft.*	
" " *Firebox* ...	86	"
TOTAL	1,037	"
Grate area ...	16·5	"



	T.	C.	T.	C.	T.	C.	T.	C.	T.	C.			T.	C.
Weight Working	9	0	11	2	11	6	11	0	9	3	...	Total	51	12
" *Light*	10	9	7	19	9	10	8	14	8	12	...	"	45	5·25

Water cap., 800 *gals.* *Coal*, 15 *cwts.*

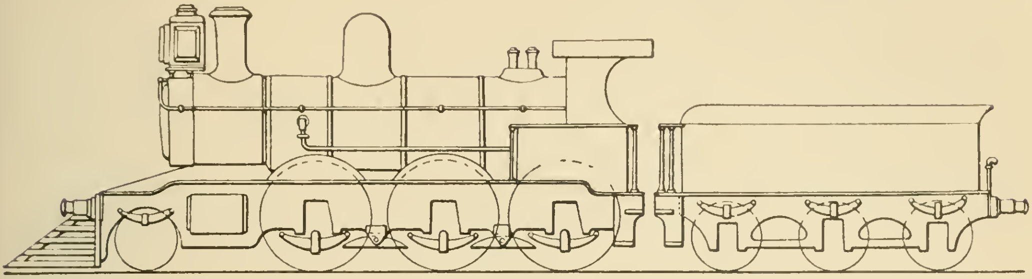


COMPOUND LOCOMOTIVES IN SOUTH AMERICA. *Plate 161.*

Fig. 7. *Class 10.*

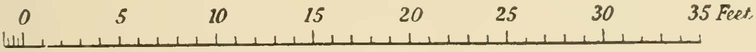
Cyls. { H.P. 18 *in.* / L.P. 26 *in.* } × 26 *in.*
Wheels, 5 *ft.* 8 *in.*
213 *Tubes*, $1\frac{7}{8}$ *in.* (*outs*).

Heating Surface of Tubes ... 1,144 *sq. ft*
" " *Firebox* ... 96 "
TOTAL ... ... 1,240 "
Grate area ... 20·13 "



Weight	T.	C.	T.	C.	T.	C.	T.	C.	T.	C.	T.	C.	T.	C.
Working	10	1	12	8	13	2	12	8	10	4	10	10	9	9
" *Light*	9	11	11	14	11	19	11	10	5	12	4	19	4	15

Total Working, 78T. 5C. *Total Light* 60 1·25 *Water cap.*, 2,500 *gals.* *Coal*, 75 *cwts.*



Compound Engine Intercepting Valve.

Fig. 8. *Improved Type.*

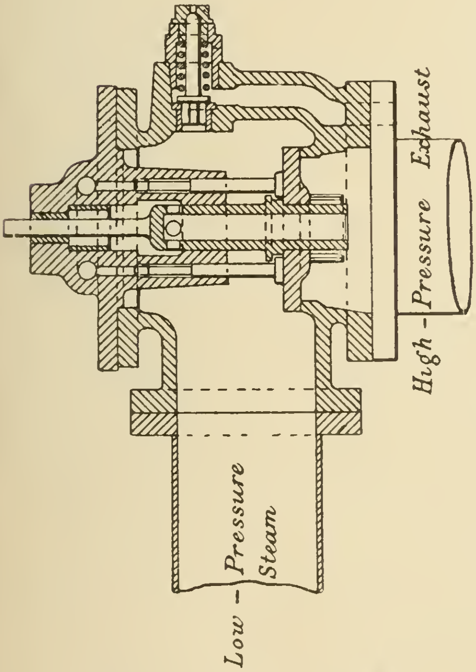
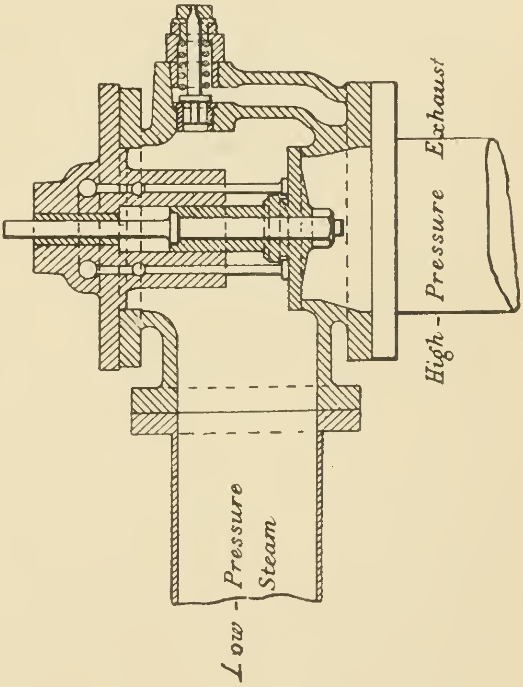
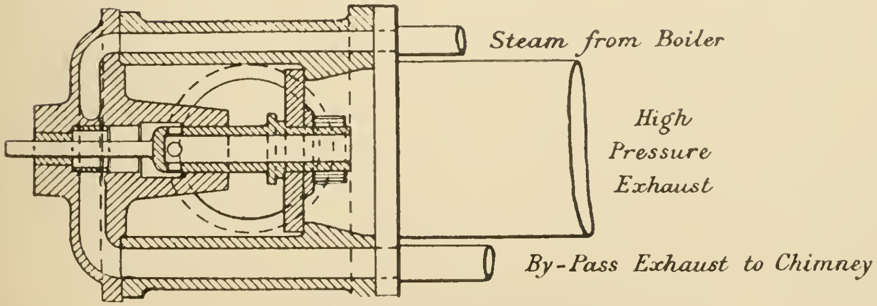


Fig. 9. *Original Type.*





100-TON UNIVERSAL TESTING MACHINE.

Fig. 2. *Jockey Weight.*

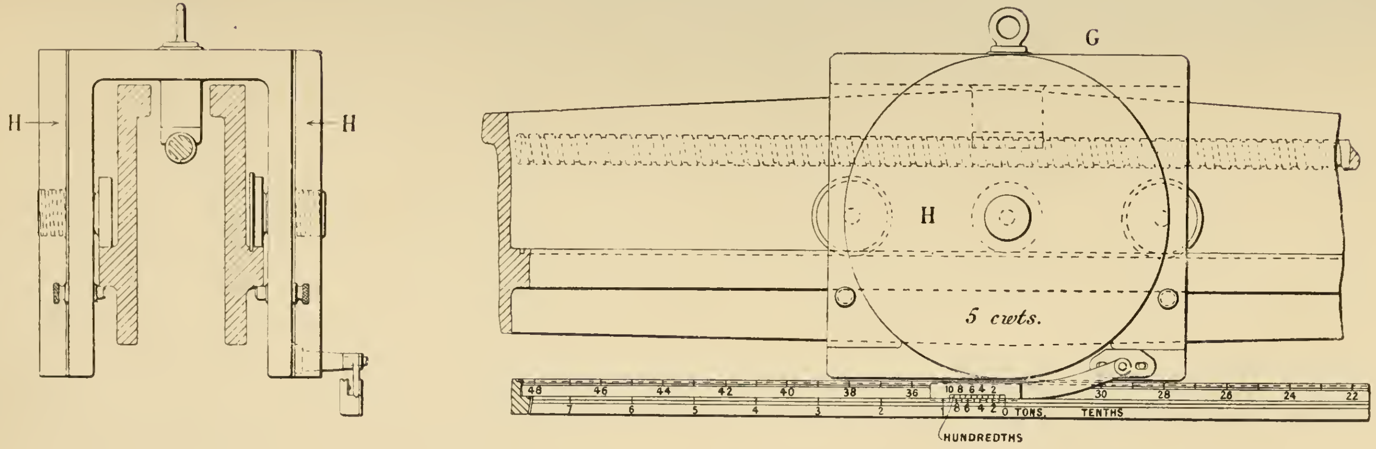
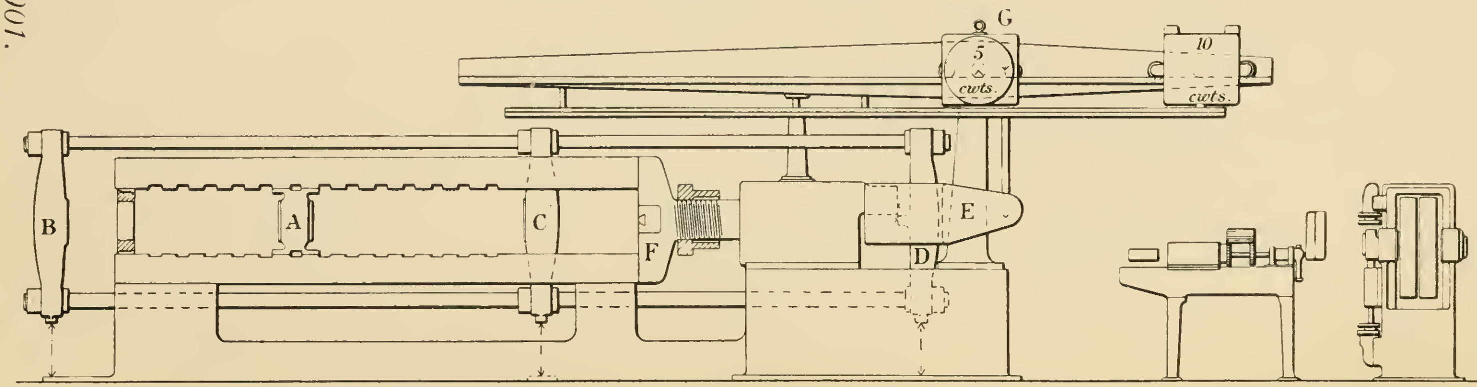


Fig. 1. *General Arrangement.*



Accumulator.

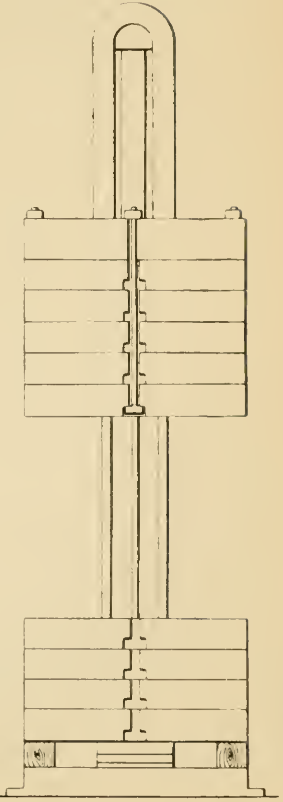


Plate 162.

100-TON UNIVERSAL TESTING MACHINE.

Fig. 3.
Torsion Apparatus.

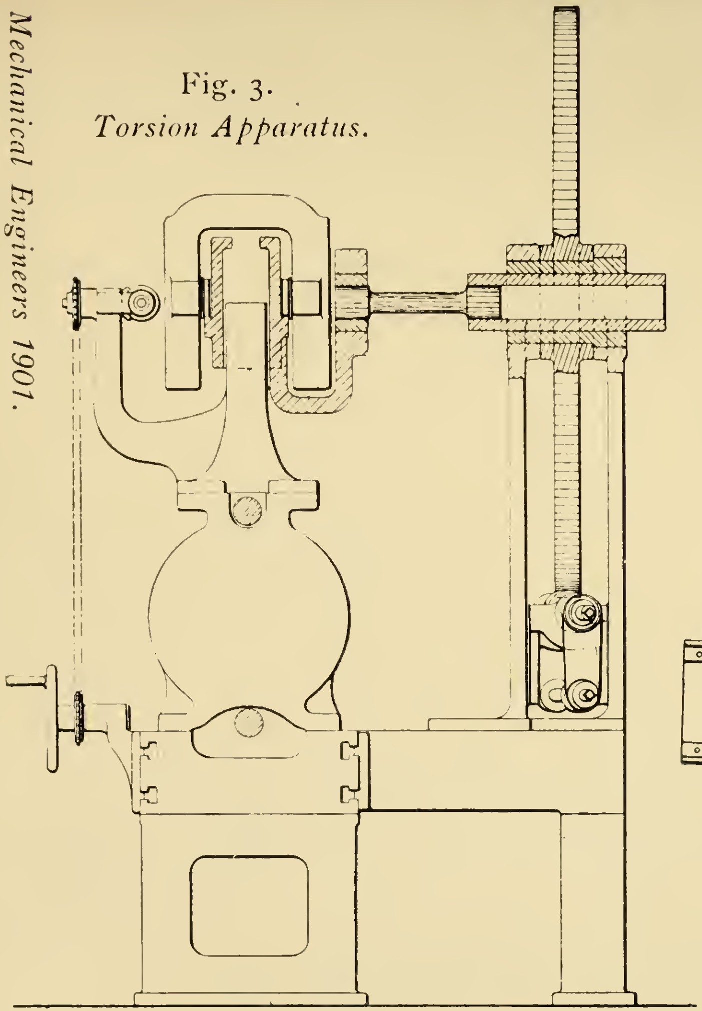


Fig. 4. *Compression Test.*

(Cast-iron column broke at 65.5 tons.)

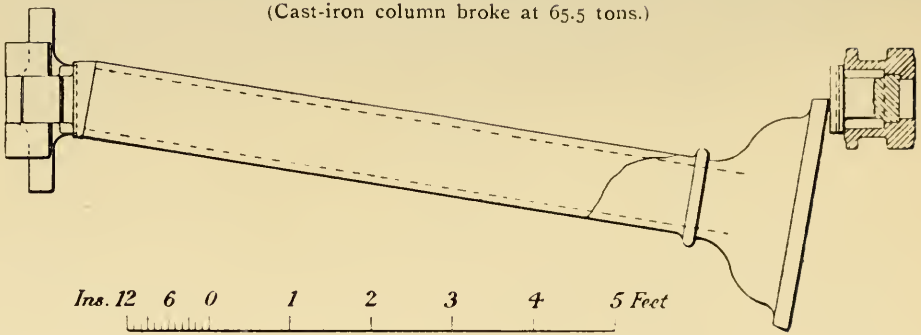


Fig. 5. *Deflection Test.*

(Beam, tested up to 100 tons upon supports 10 feet apart, deflected 1 inch, and took a permanent set of ½ inch.

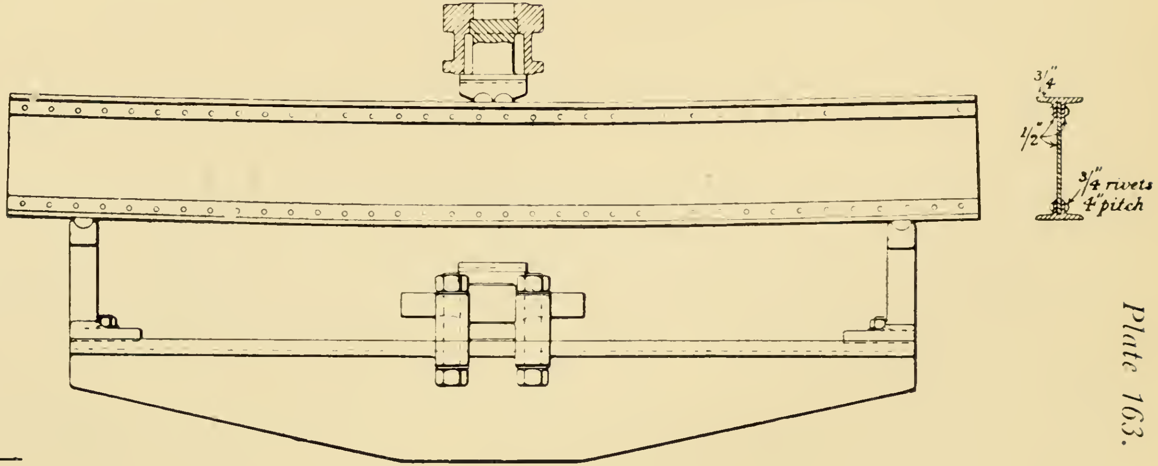


Fig. 6. *Blocks for Single-Shearing Test.*

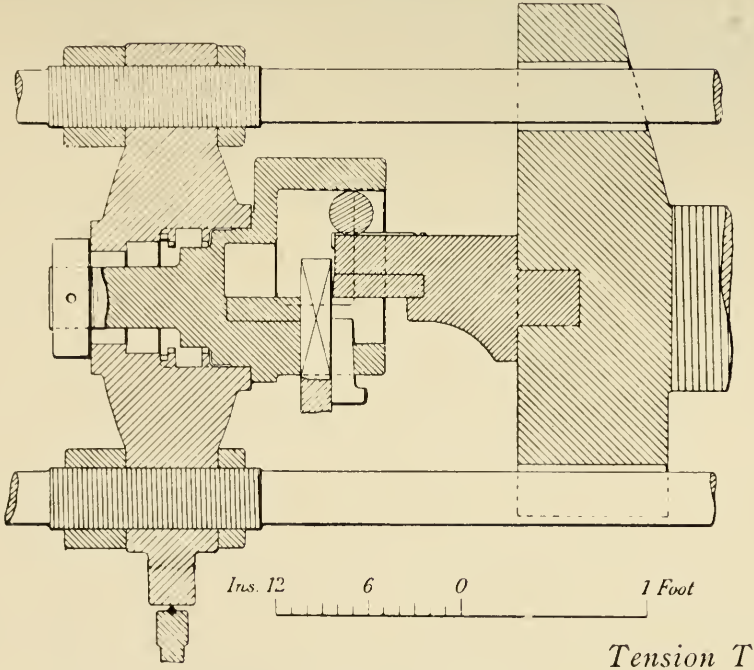
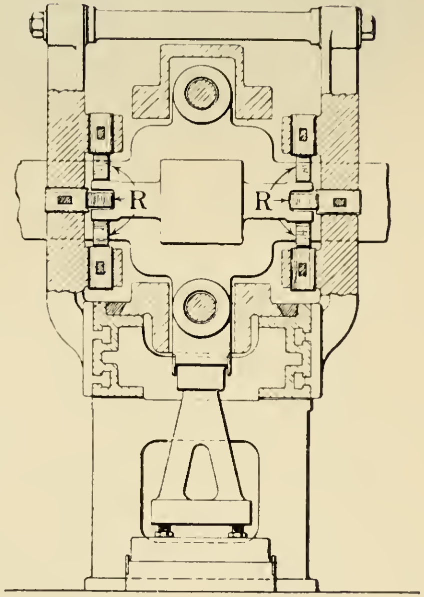
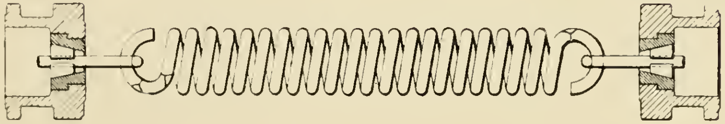


Fig. 7. *Roller Stay.*



Tension Tests (Scale 1/32nd).

Fig 8. *Helical Spring of 1½ inch round steel.*



Same Spring held by end coils.

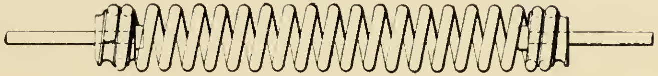
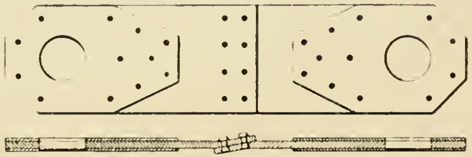


Fig. 9.

Double-riveted Lap Joint, with rivets ¾ inch diameter.

With 8 steel rivets in single shear, took a permanent set at 46 tons, and fractured at 90 tons.

With 8 iron rivets in single shear, took a permanent set at 42 tons, and fractured at 75 tons.



100-TON UNIVERSAL TESTING MACHINE.

Fig. 10. *Machine in the Watt Laboratory, Glasgow University.*

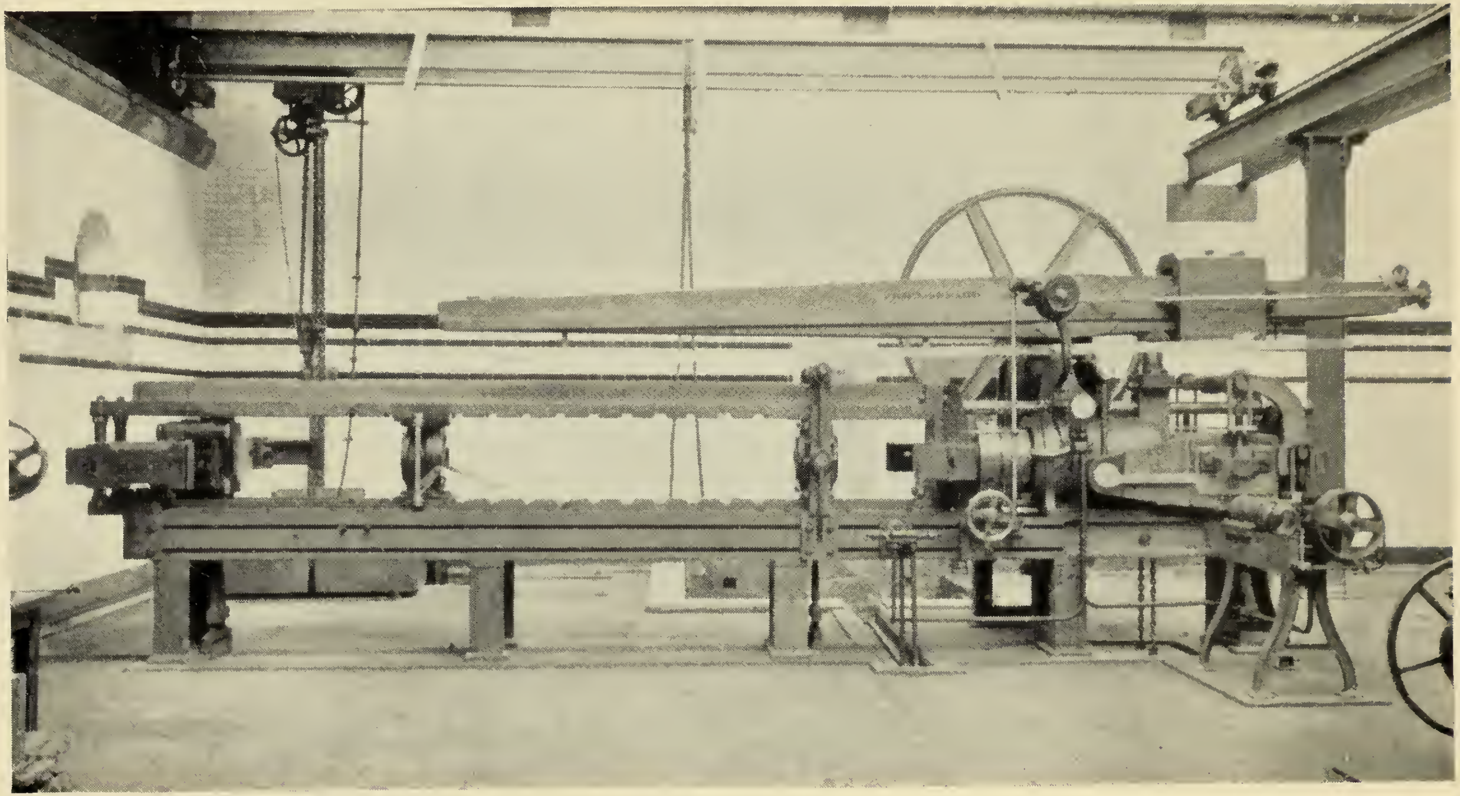


Fig. 1. *Beam Knee Riveter with independent tail piece.*

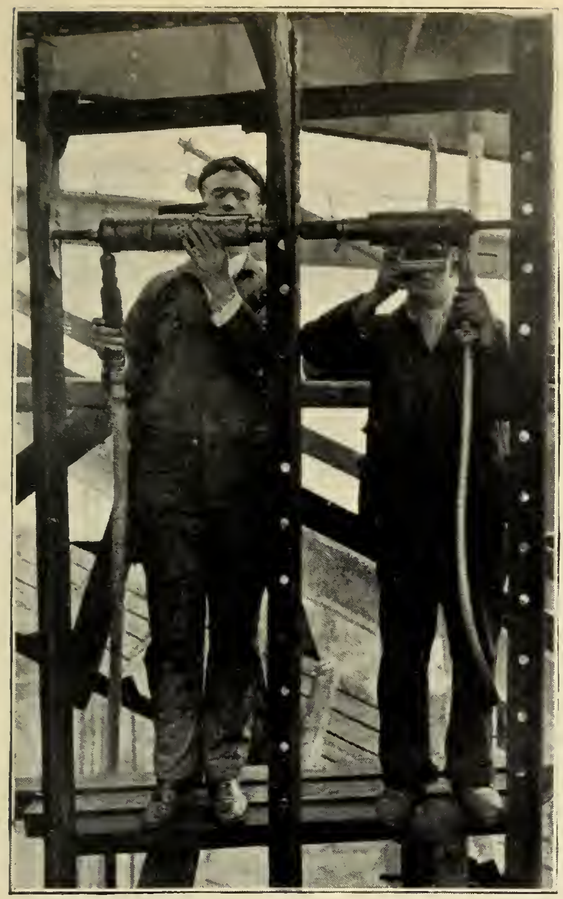


Fig. 2. *Bridge Drilling.*

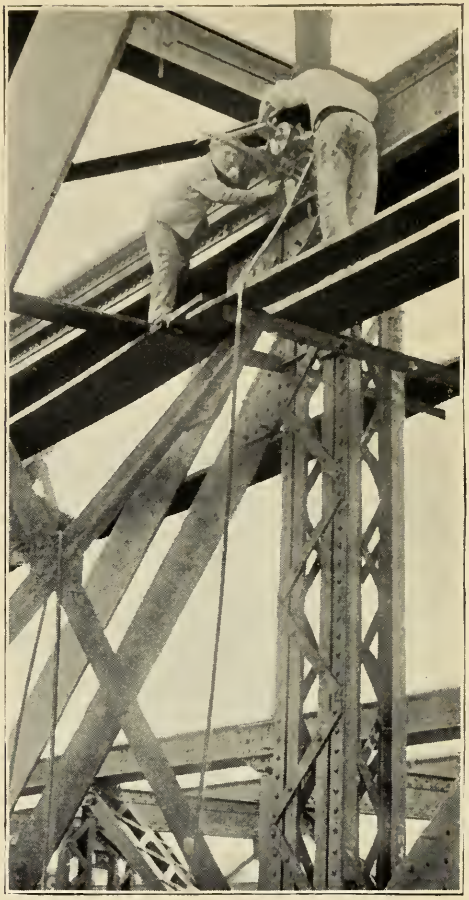


Fig. 3. *Bridge Drilling.*

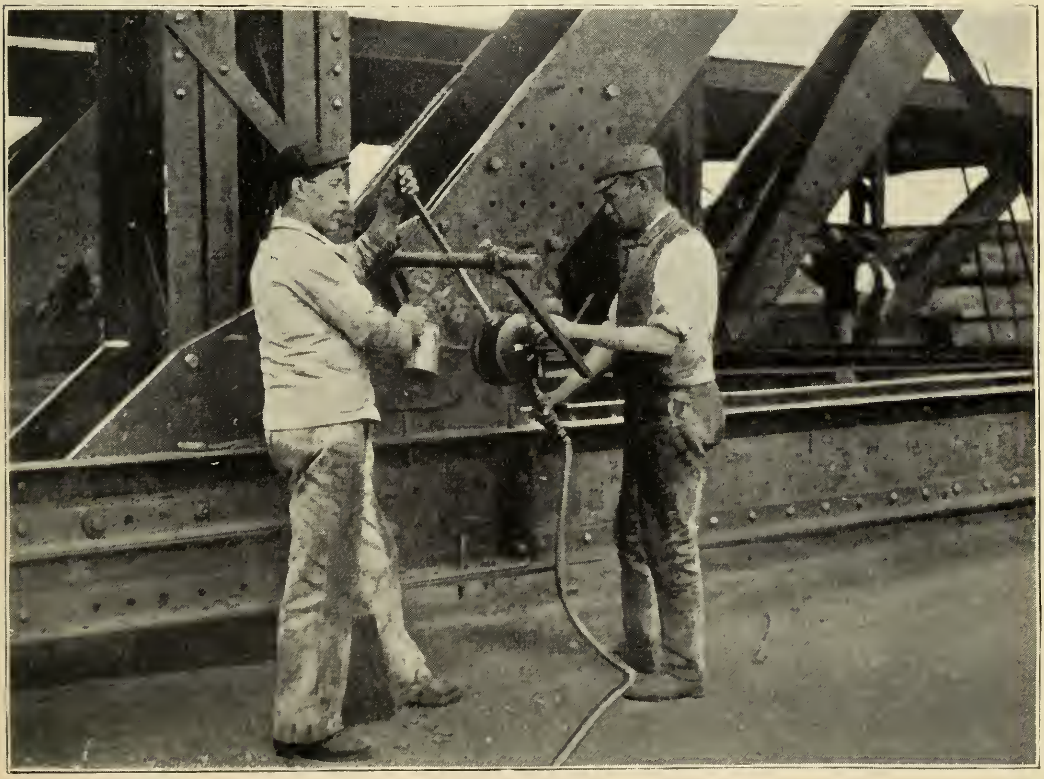


Fig. 4. *Drilling, Riveting, and Chipping between Decks.*

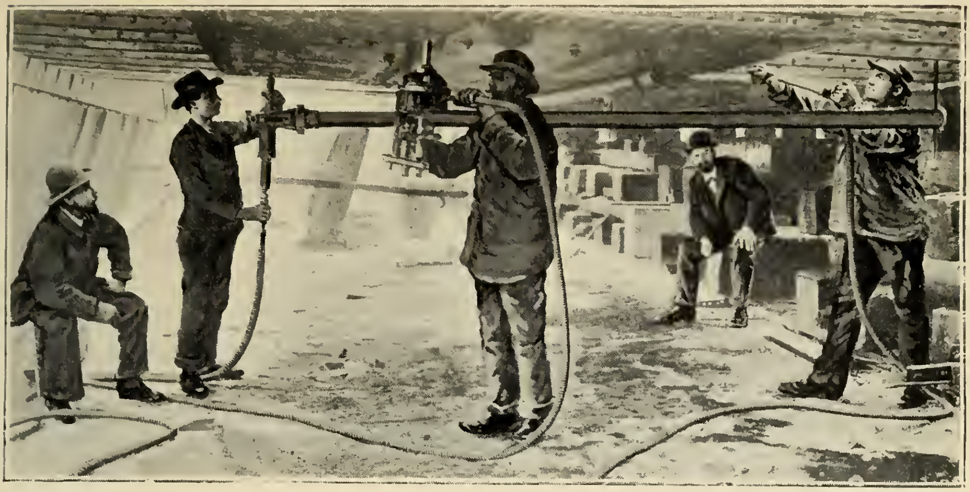


Fig. 5. *Tank Riveting.*

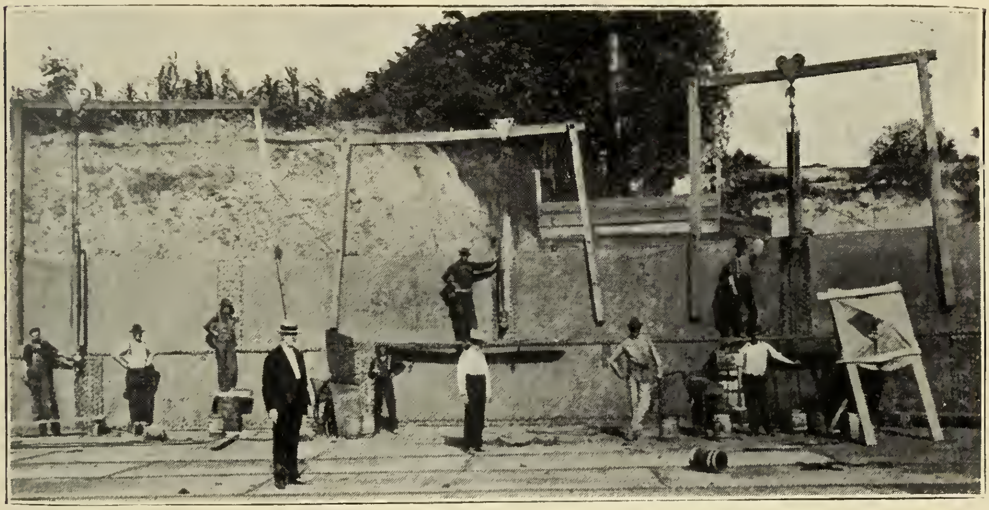
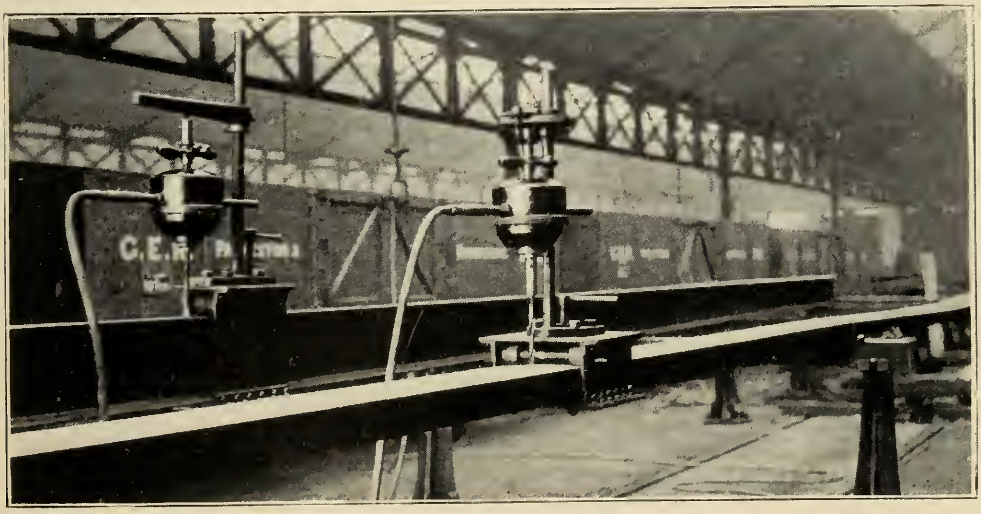


Fig. 6. *Travelling Drill-carriages on Girders.*



PNEUMATIC RIVETING.

Fig. 7. *Tube Cutter.*

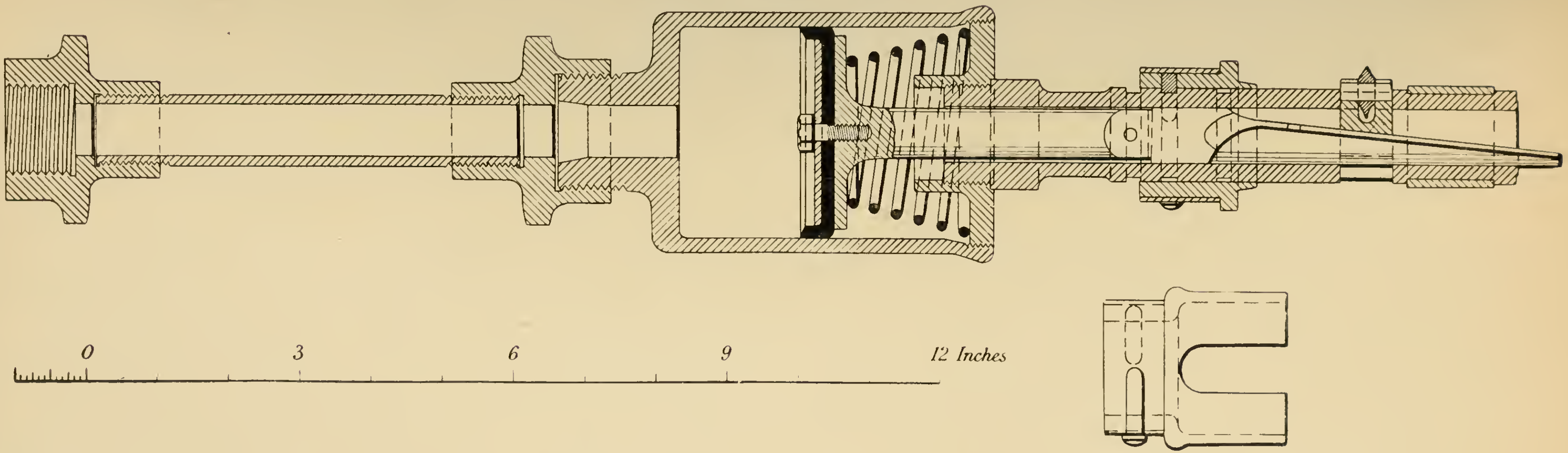
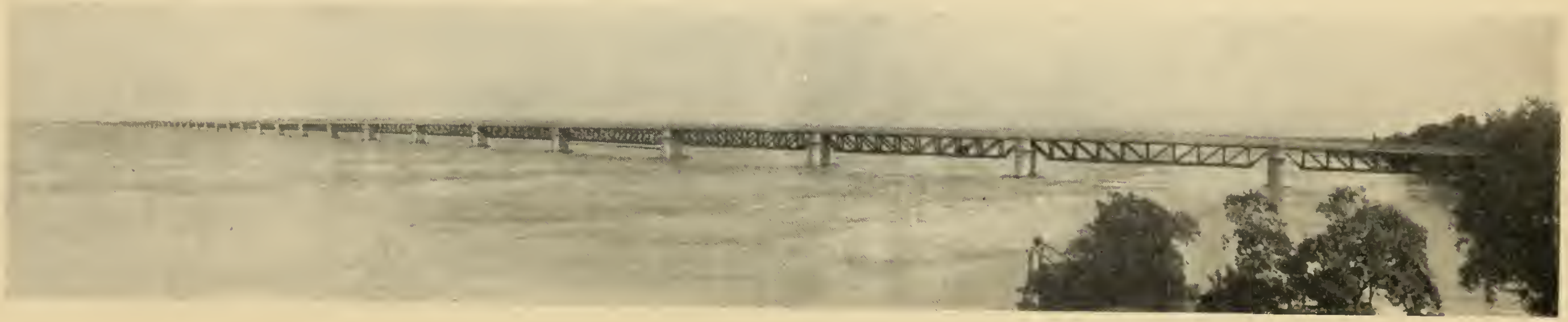


Fig. 8. *Godaveri Bridge, Rajahmundry.*
All the bottom booms were riveted by pneumatic machinery.



CANADIAN AGRICULTURAL MACHINERY.

Seeders.

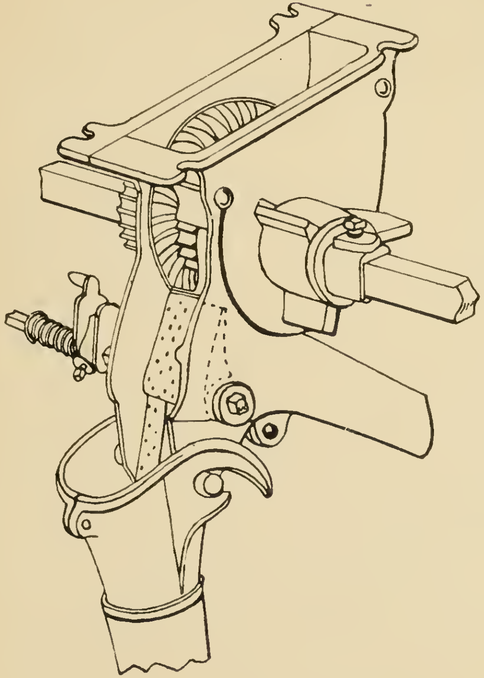


Fig. 1. *Hoe Drill.*

Detail of Feed from Seed-box into the Tubes.

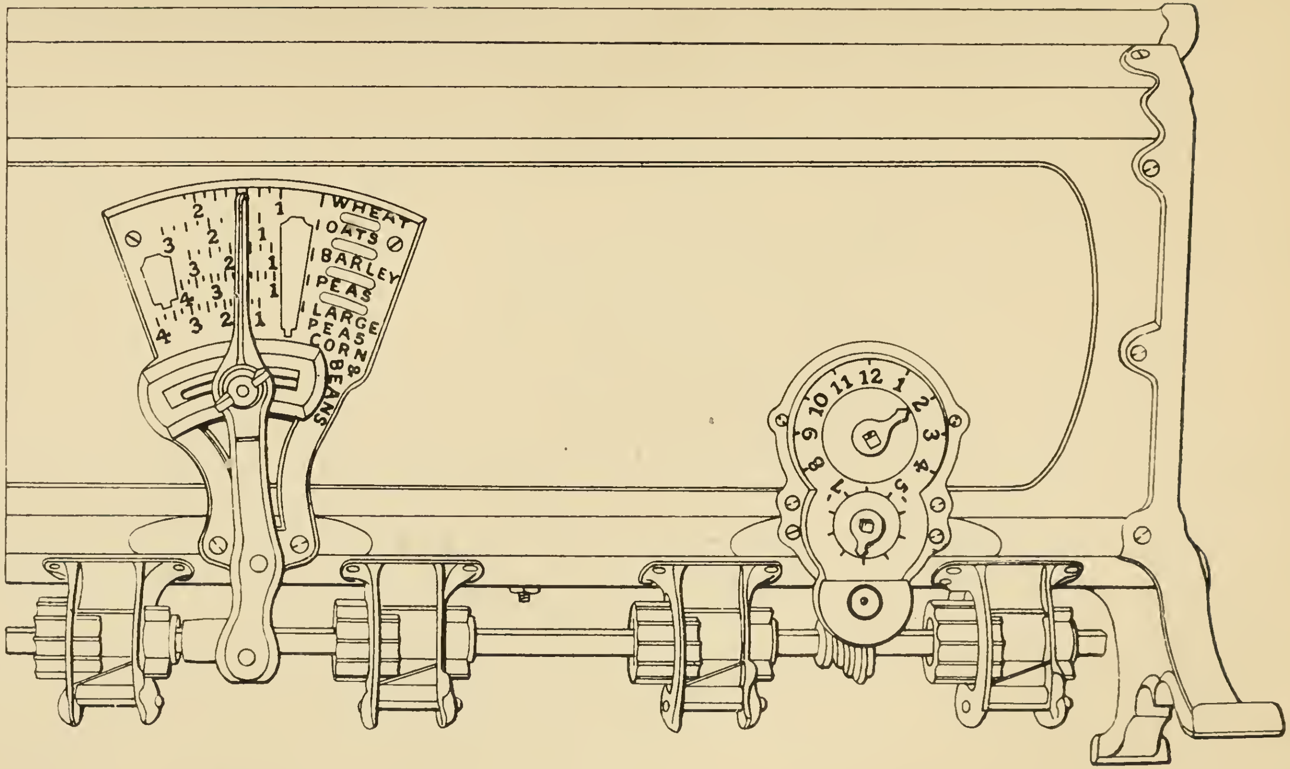


Fig. 2. *Arrangement for Regulating the Flow of Seed, and Dial for Indicating Number of Acres Sown.*

Mechanical Engineers 1901.

CANADIAN AGRICULTURAL MACHINERY.

Mowers.

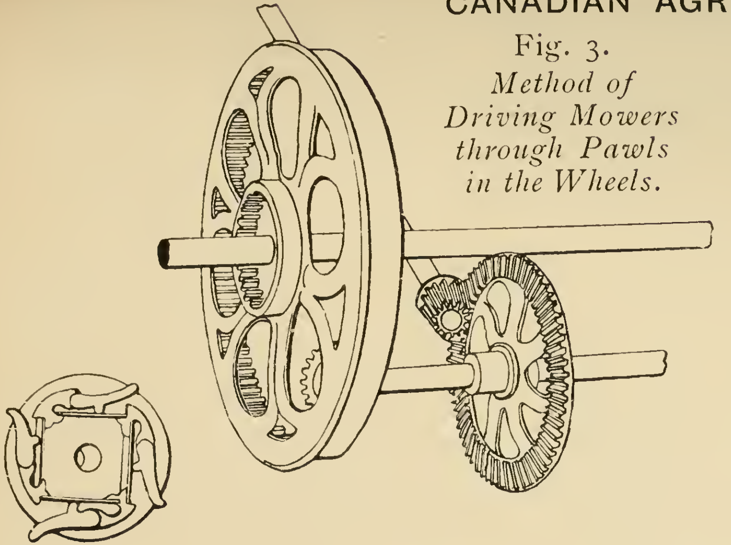
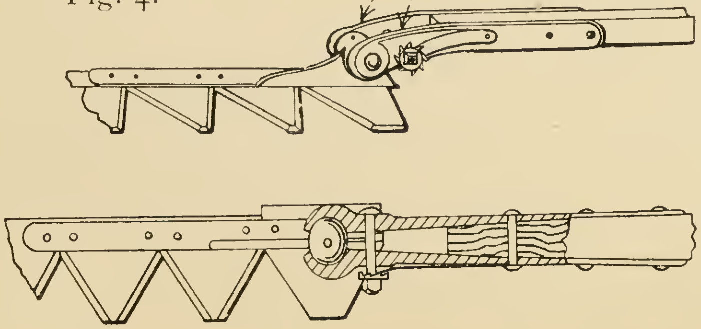


Fig. 3.
Method of Driving Mowers through Pawls in the Wheels.



Two leading methods of attaching the Connecting-rod to the Knife.

Fig. 4.

Forged Steel Jaws

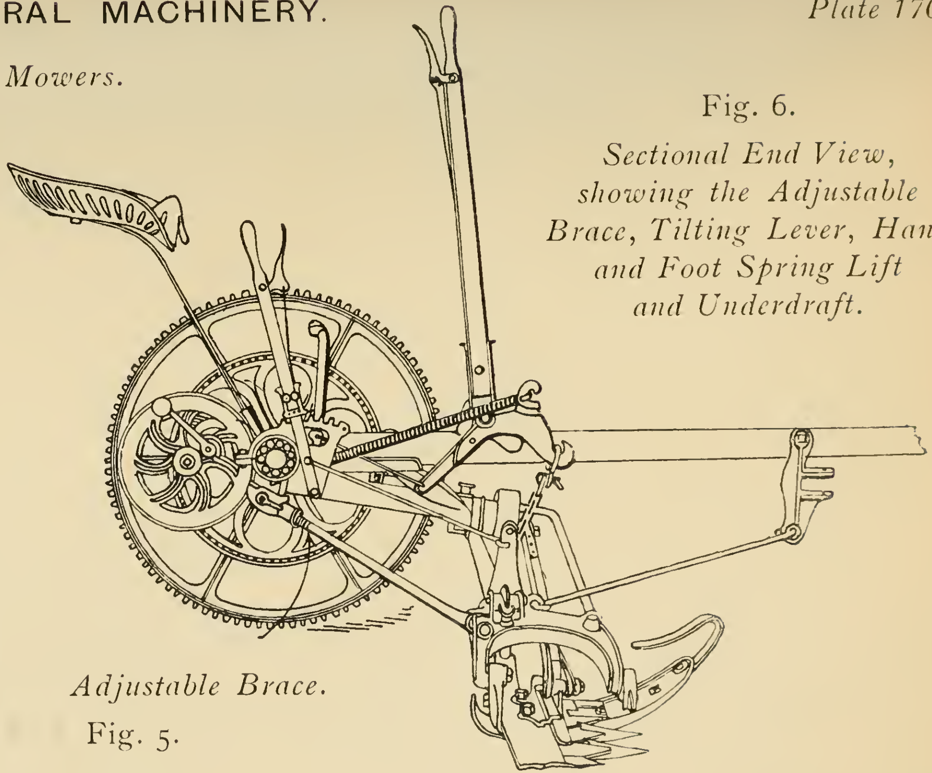
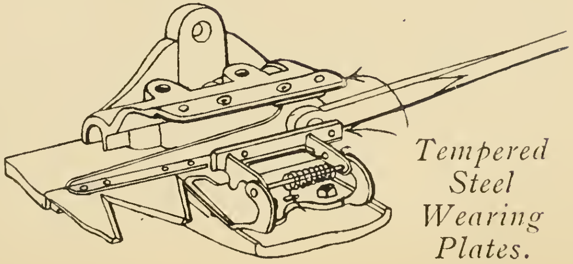


Fig. 6.
Sectional End View, showing the Adjustable Brace, Tilting Lever, Hand and Foot Spring Lift and Underdraft.



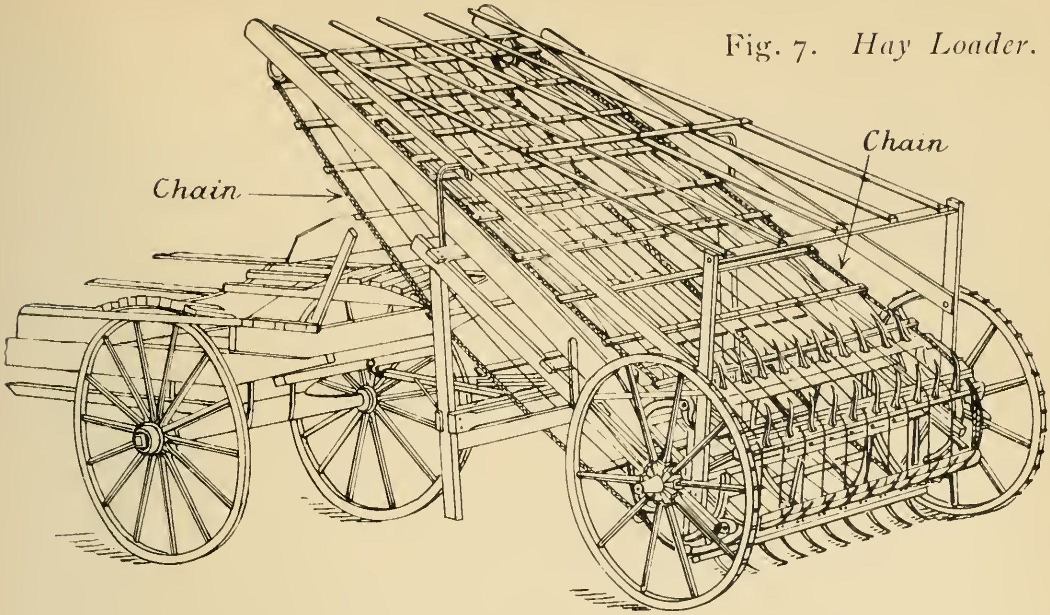
Adjustable Brace.

Fig. 5.

Tempered Steel Wearing Plates.

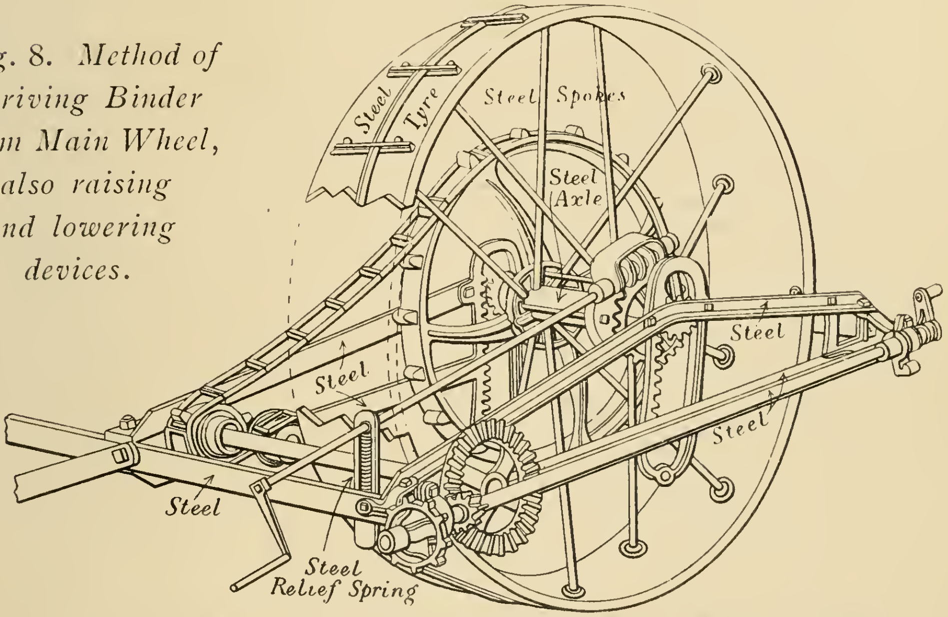
Mechanical Engineers 1901.

Fig. 7. *Hay Loader.*



Binders.

Fig. 8. *Method of Driving Binder from Main Wheel, also raising and lowering devices.*



Arrangement for Elevating Heavy and Tangled Grain.

Allowing for expansion of space between elevators with a constant tight hold on the grain.

Fig. 9.

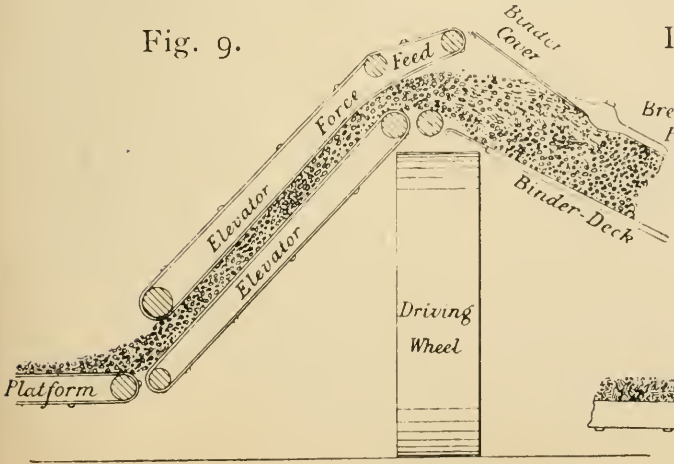
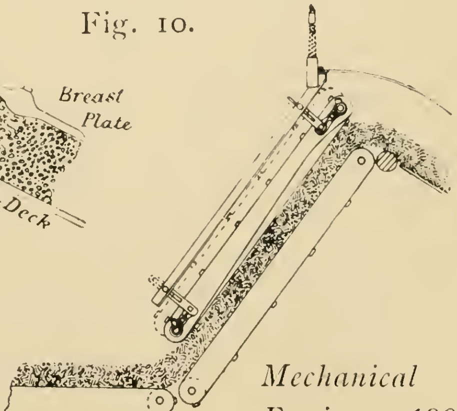


Fig. 10.



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Knotting Mechanisms.

Fig. 11. *Massey-Harris.*

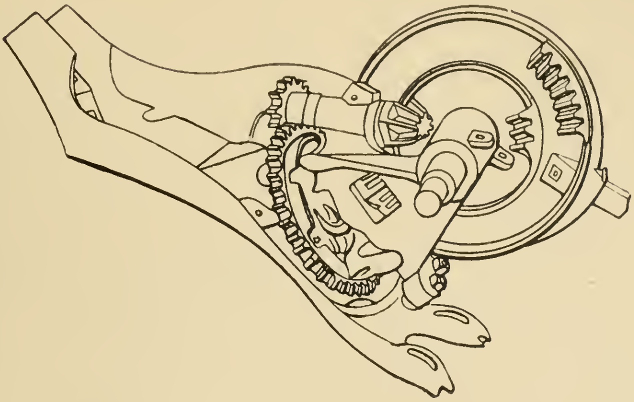


Fig. 12. *Frost and Wood.*

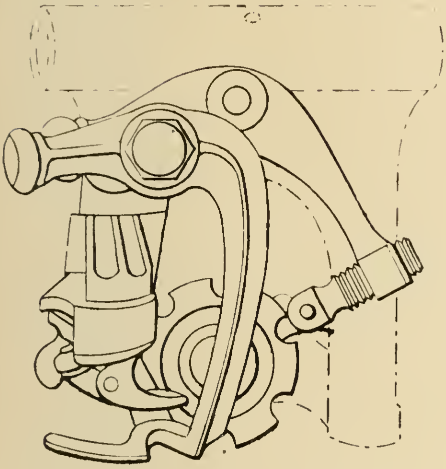
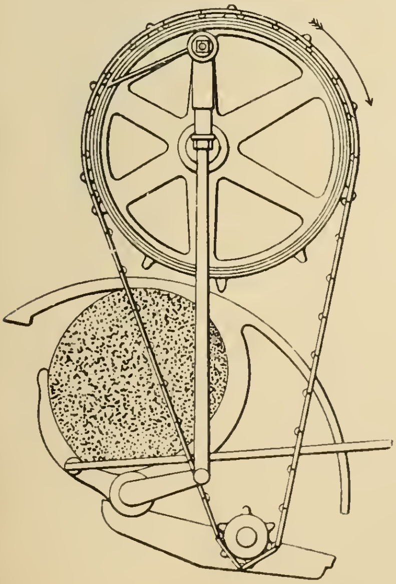
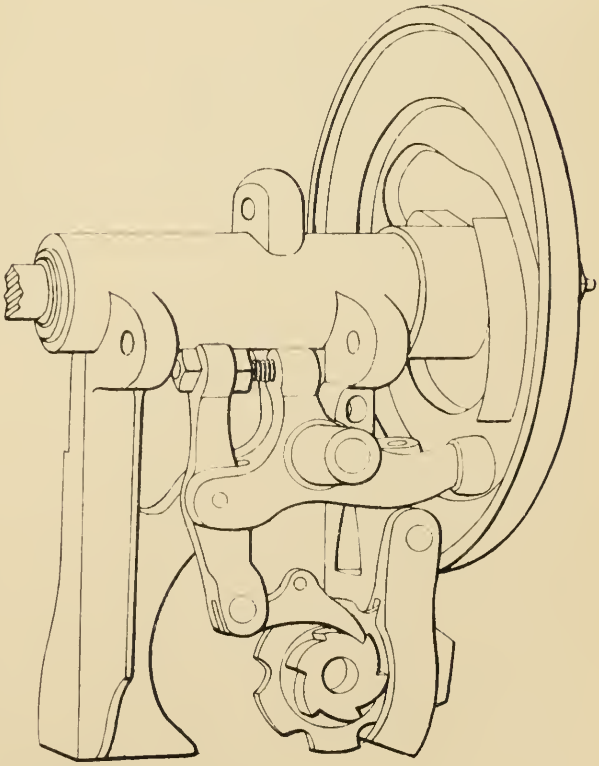


Fig. 14. *Maxwell.*

Fig. 13. *Frost and Wood.*





CANADIAN AGRICULTURAL MACHINERY. *Plate 173.*

Application of Roller and Ball Bearings in various Machines.

Fig. 15. *Mower.*

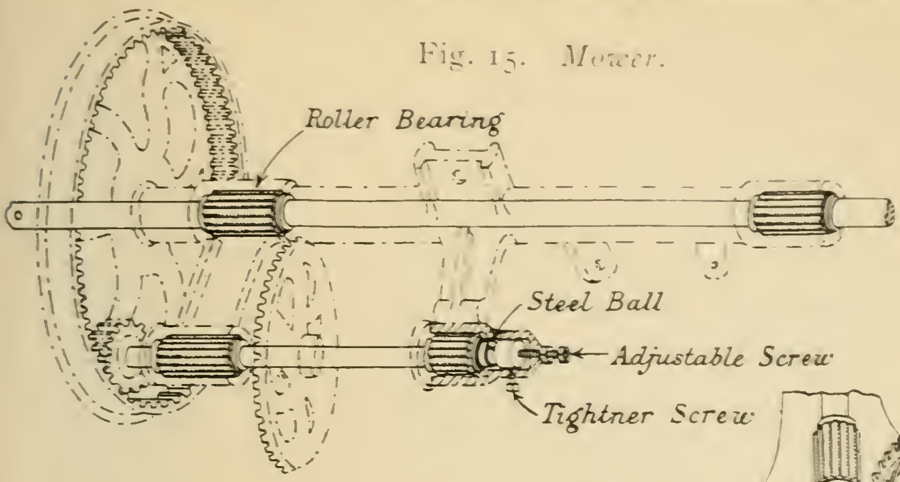


Fig. 16. *Mower.*

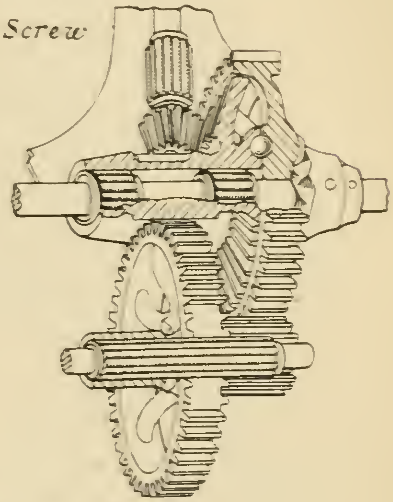


Fig. 17. *Binder.*

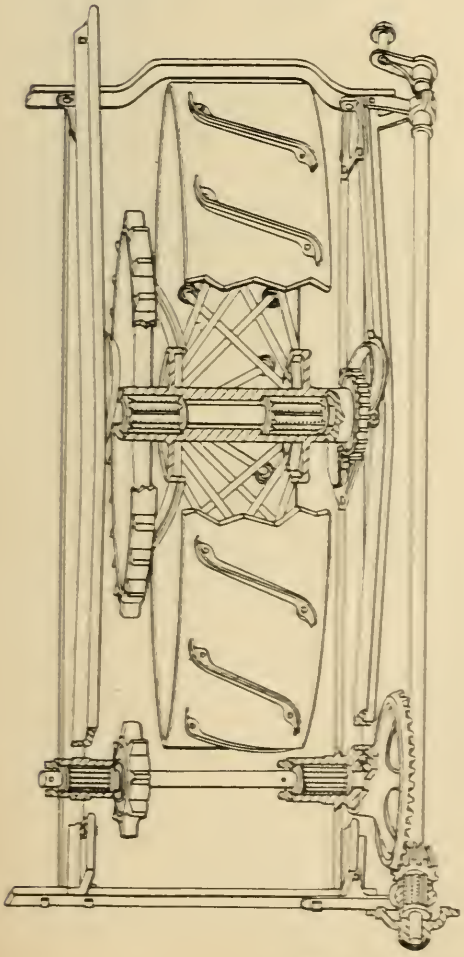
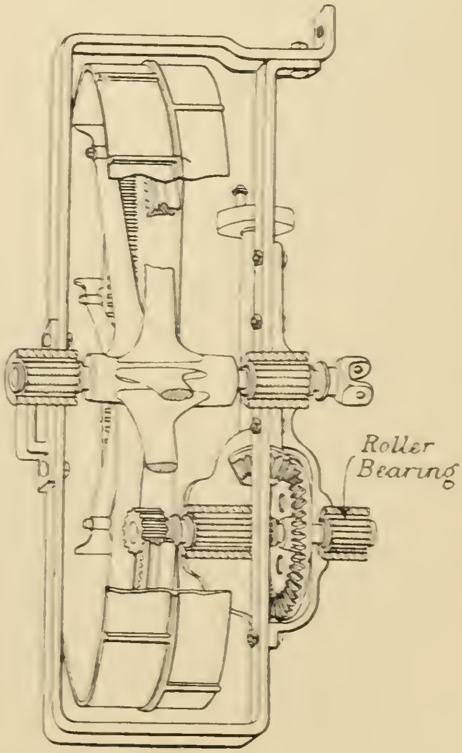
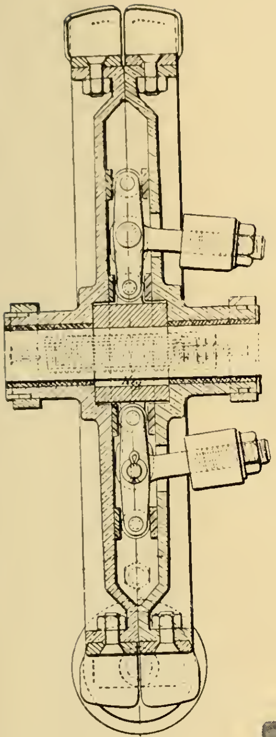


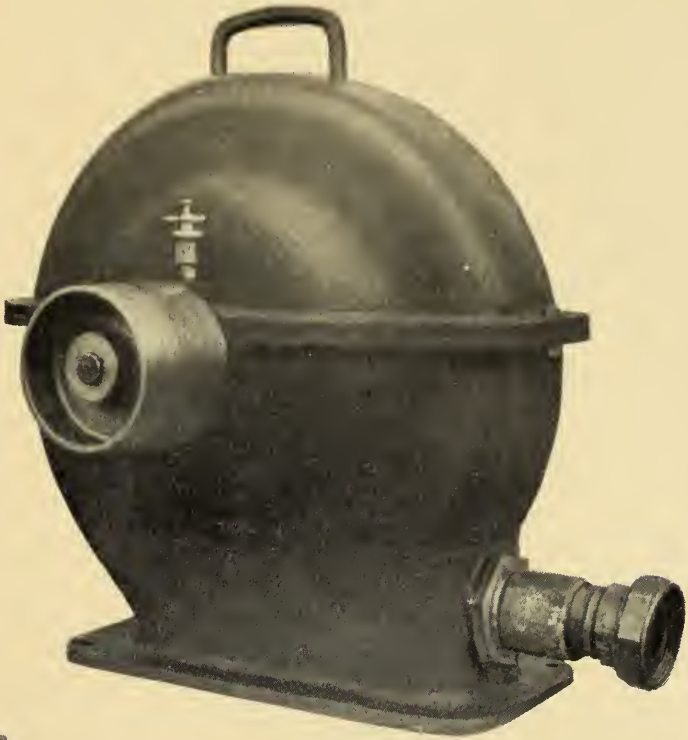
Fig. 18. *Reaper.*

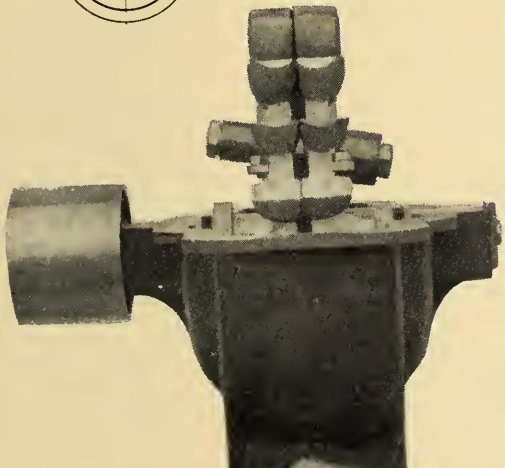


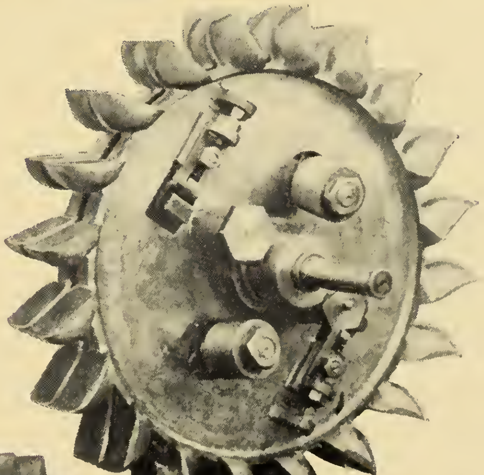
Mechanical Engineers 1901.

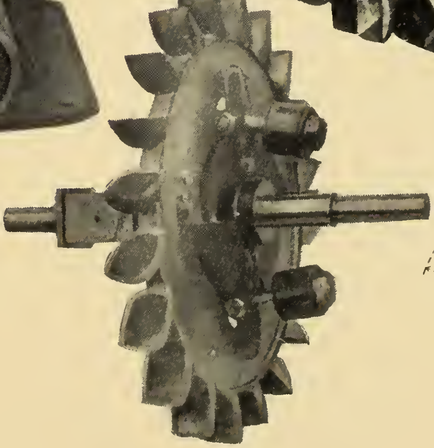
SELF-REGULATING WATER WHEEL. *Plate 174.*

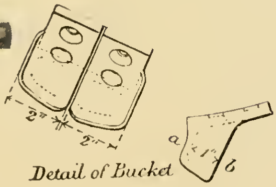




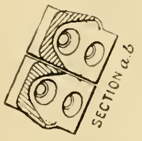


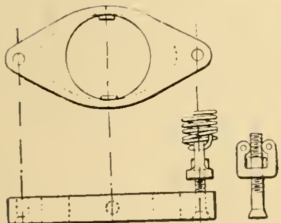






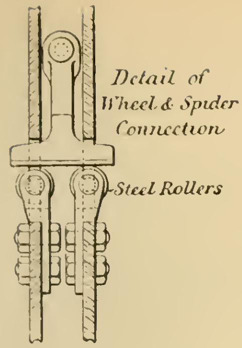
Detail of Bucket

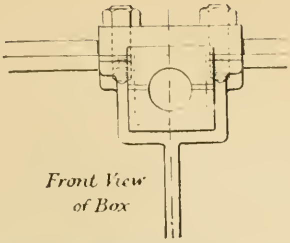


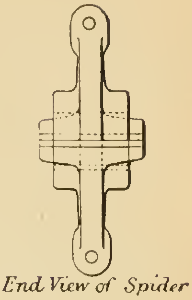


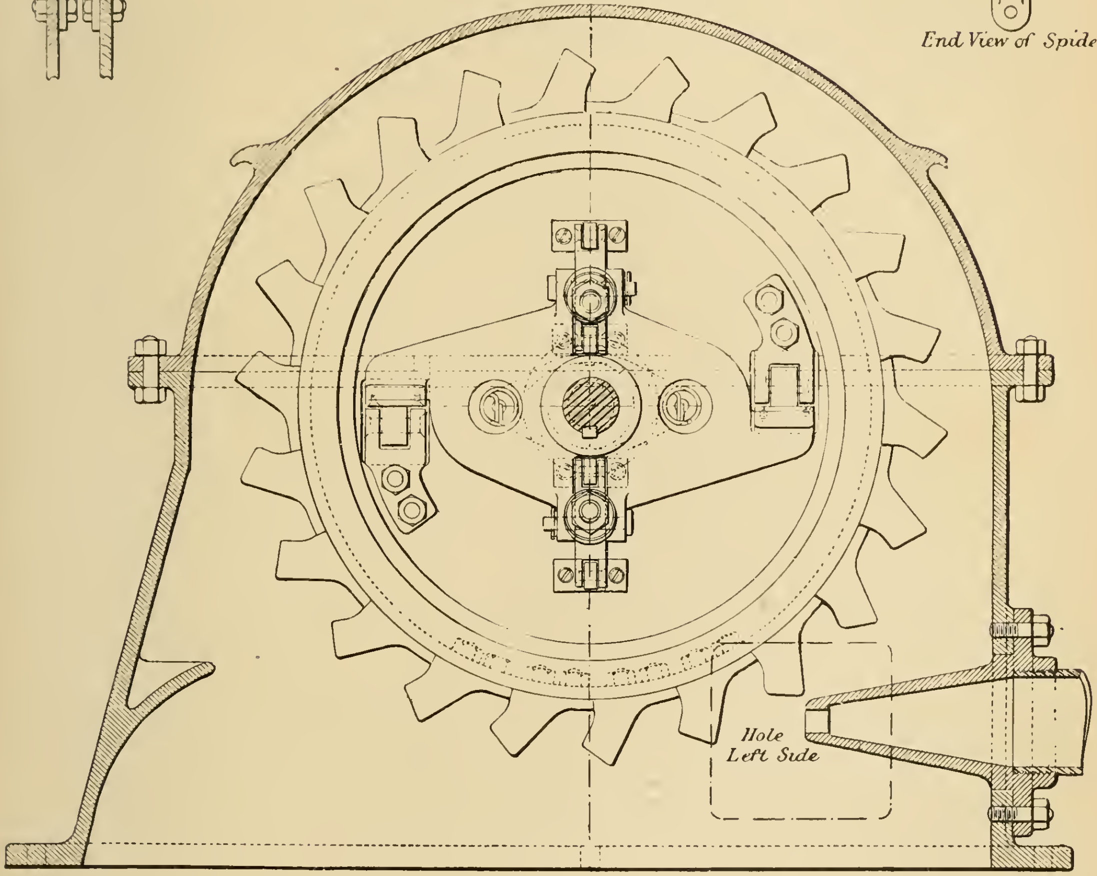
Detail of Spring Adjustment

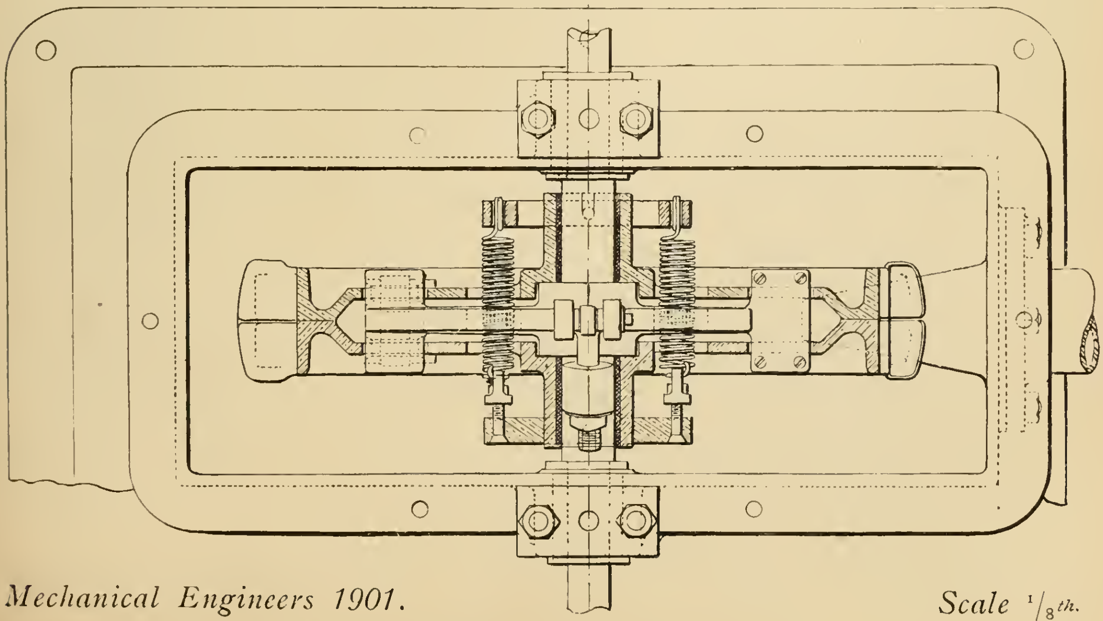
SELF-REGULATING WATER WHEEL. *Plate 175.*











Mechanical Engineers 1901.

Scale $^1/_8$ *th.*

The Institution of Mechanical Engineers.

PROCEEDINGS.

October 1901.

The first Ordinary General Meeting of the Session was held at the Institution on Friday, 18th October 1901, at Eight o'clock p.m.; William H. Maw, Esq., President, in the chair.

The Minutes of the previous Meeting were read and confirmed.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following ninety-six candidates were found to be duly elected:—

MEMBERS.

Beck, Isaac,	Sheffield.
Borham, William Evans,	Mysore, India.
Buckham, George Thomas,	London.
Clayton, James,	Braintree.
Cloake, William Henry,	London.
Collet, Harold van Brienen,	London.
Dawson, Lieut. Arthur Trevor, late R.N.,	London.
Dunn, James,	Barrow-in-Furness.
Goodier, Frank,	São Paulo, Brazil.
Hill, Joseph,	Derby.

Jacobs, Lieut. Joseph John, R.E.,	Sheerness.
Lindsay, Robert,	Dundee.
Macdonald, Fitz Charles,	Rangoon.
Macmillan, Colin Campbell,	Glasgow.
McKechnie, James,	Barrow-in-Furness.
Peart, John,	Darlington.
Reid, Robert Shaw,	Glasgow.
Robinson, John James,	Durban, Natal.
Talbot, Benjamin,	Leeds.
Vaughan, Cedric,	Millom, Cumberland.
Wadia, Nusserwanjee Nowrosjee,	Bombay.
Webb, Thomas Henry,	Loughborough.

ASSOCIATE MEMBERS.

Allan, George, Jun.,	Birmingham.
Arnold, Frederick Nathaniel,	London.
Atherton, Ernest Stanley,	Calcutta.
Atherton, William Henry,	Glasgow.
Bartley, Bryan Cole,	Johannesburg.
Boot, James Noel,	London.
Budding, Brice Henry, Jun.,	London.
Carnegie, Francis,	Woolwich.
Cartmell, John Monkhouse,	Glasgow.
Davidson, John,	Manchester.
Dawson, Henry Watson,	Manchester.
Dickinson, Henry Winram,	London.
Digby, William Pollard,	Berlin.
Hardwick, Eustace James,	London.
Hawks, Nicholas Swanson,	London.
Henderson, Robert,	Edinburgh.
Heward, Sidney Edgar,	London.
Heydeman, Harry George Julius,	Maritzburg, Natal.
Jeffreys, Richard Rice Vesey,	Bulawayo.
Johnson, Frederic Adolph,	Madison, Wis., U.S.
Kenrick, Archibald, Jun.,	Leeds.
King, Ernest,	London.

Kitchin, John William,	Devonport.
Kremnitz, Harry,	Leeds.
Leeds, Edward Lambert,	London.
Mills, Frank,	Taiping, Perak.
Naylor, John Alfred,	London.
Page, Hugh Algernon,	London.
Page, James Handford,	Liverpool.
Palmer, Alfred,	Sheffield.
Percy, Frank,	Wigan.
Pritchard, Roger Cromwell,	London.
Rainforth, William Frederick,	Vienna.
Rudder, Frank Percy,	Manchester.
Saccaggio, Pietro Celestino,	Buenos Aires.
Smyth, William Miller Campbell,	London.
Spencer, Arthur Lincolne Hitchcock,	Hitchin.
Spencer, William Edward Spencer Hitchcock,	London.
Stanier, William Arthur,	Swindon.
St. Paul, Clarence,	Bombay.
Walker, Alfred,	London.
Walker, Robert Hugh,	Neuchatel.
Waller, William,	London.
Walsh, Thomas,	St. Anne's-on-Sea, Lancs.
Young, Horatio Edwin,	Huddersfield.

GRADUATES.

Atherton, William Herbert,	Warrington.
Beckett, Joseph Edge,	Sheffield.
Bennett-Powell, Percival Gordon,	London.
Berners, Hamilton Hugh,	London.
Bowen, Charles William,	London.
Bowman, Harold Edelsten,	Preston.
Bulleid, Oliver Vaughan Pugh,	Doncaster.
Burton, Charles Kingsley,	Bradford.
Cooper, George Seton Halcott,	London.
Faulkner, Francis Claude,	Rugby.

Greenwood, Frederick George, . .	London.
Howl, Frederick William, . .	London.
Hunter, John Chalmers, . . .	Glasgow.
Laubach, Philip Alfred, . . .	London.
McGregor, James, ...	Glasgow.
Nevill, Stanley Sharp, . . .	London.
Peacock, Jesse Butler, . . .	Birmingham.
Peake, Ashley Crosthwaite, . .	London.
Prevôst, Alfred Thomas, . . .	London.
Ritchie, John McAuslan, . . .	Sydney.
Sandaljian, Bedros, ...	London.
Smith, Alfred John, ...	King's Lynn.
Turner, Ernest William, . . .	Peterborough.
Turner, William Wallace, . .	Sydney.
Wadams, Samuel James, . . .	Birmingham.
Wallace, Cecil Percy, . . .	London.
Warwick, Percy Walter, . . .	London.
White, Percy Wilson, . . .	London.
Willey, Leonard Arthur, . . .	London.

The President congratulated the Members on the large increase of their numbers, the elections of all classes having this year amounted to 449, exceeding the number elected in 1900 by 84.

Transferences.

The President announced that the following three Transferences had been made by the Council since the last Meeting :—

Associate Members to Members.

Beven, Alfred Nugent, . . .	Junin, Chile.
Davidson, John McKenzie, . .	Karachi.

Associate to Member.

Cooper, Thomas Lancelot Reed, .	Glasgow.

The following Paper was then read and discussed:—

"Second Report to the Gas-Engine Research Committee;" by Professor Frederic W. Burstall, *Member*, of Birmingham University.

At the close of the Meeting the President announced that, as the Discussion had not been concluded, an Extra Meeting would be held on Friday, 1st November.

The Meeting terminated at a Quarter to Ten o'clock. The attendance was 142 Members and 77 Visitors.

PROCEEDINGS.

1st November 1901.

An Extra Meeting was held at the Institution on Friday, 1st November 1901, at Eight o'clock p.m.; William H. Maw, Esq., President, in the chair.

The Minutes of the previous Meeting were read and confirmed.

The President was glad to announce that Lord Kelvin had accepted the Council's nomination as an Honorary Life Member. He was also pleased to state that Mr. Herbert A. Humphrey and Mr. Dugald Clerk had accepted invitations to join the Gas-Engine Research Committee.

The Discussion was resumed and concluded on Professor Burstall's Second Report to the Gas-Engine Research Committee.

The Meeting terminated at a Quarter to Ten o'clock. The attendance was 94 Members and 48 Visitors.

SECOND REPORT TO THE GAS-ENGINE RESEARCH COMMITTEE.

By Professor FREDERIC W. BURSTALL, *Member*,
of Birmingham University.

In the First Report* of the Gas-Engine Research Committee an account was given of the apparatus and engine which were used for the experiments, and of a small number of preliminary experiments made in order to pave the way for a more extended and complete series. The engine used throughout the research was one specially constructed by Messrs. Fielding and Platt of Gloucester, and was arranged so that the compression could be altered from about 30 lbs. per square inch to about 105 lbs. per square inch. The normal speed for the engine was 200 revolutions per minute, the diameter of the cylinder was 6 inches, and the stroke was 12 inches.

The tests were all made with lighting gas, which was supplied from a gas-holder capable of holding about 100 cubic feet. This quantity would suffice to run the engine at full power for about fifty minutes; in general, the tests lasted for half an hour. In most cases such short tests would not be desirable, but it must be borne in mind that, in a plant such as was used in the research, it is possible to obtain such steady conditions that the length of a test can be shortened without in any way affecting its accuracy. In the First Report a full account of the apparatus and the methods employed for the calibration of all instruments was given; for the objects of the present Report all that is required will be to state that in addition to such measurements as quantity of gas, indicated and brake power, number of revolutions and explosions, temperature and quantity of jacket water, the air supplied was measured by a wet meter, and an analysis was made of the exhaust gases. Some alterations and additions have been made to the apparatus formerly described. An account of these changes is now added.

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* Proceedings 1898, page 209.

Ignition.—In the First Report some account was given of the failure to obtain a satisfactory electric-ignition. The time expended on these unsuccessful experiments was not altogether wasted, as the experience then gained led to the design of a perfectly satisfactory ignitor. In the previous experiments, a high-tension spark was employed, and thus great difficulties were encountered in order to keep up the insulation. The present electric-ignitor is worked with a spark which is produced when a low potential circuit containing iron is broken. The difficulty with this method is to produce the break of the circuit inside the cylinder. Attempts were made to do this by means of the motion of the piston, but without success. The ignitor is shown in Figs. 1 and 2. It consists of a threaded plug, which screws into the cylinder in the position where the ordinary ignition tube is placed. From the lower extremity of this plug project two steel rods about three inches in length, the rods being connected together by a short bridge-piece in which is fixed a platinum tip. The difficulty in the construction of the ignitor was to insulate the moving contact. This was effected by insulating the whole of the upper part of the plug containing the gland, through which the sliding rod moves from the lower part which screws into the cylinder. The insulation is formed of mica discs, which are placed both above and below a ring forming part of the upper plug. These mica discs are forced down on the ring by means of a nut threaded on to the lower plug. The moving contact consists of a steel rod tipped with platinum, and passing through a gland packing in order to prevent leakage of gas. The packing is a mixture of asbestos and plumbago. The moving rod is forced down by a spiral spring, and lifted by a bell-crank lever. Owing to the fact that the rod must be insulated from the body of the cylinder, the lever has also to be insulated; it is therefore made in two parts, which are fastened together by bolts passing through ebonite washers. The lower end of the bell-crank lever has attached to it a roller which presses on to the exhaust cam. The time of the passage of the spark is altered by fixing the roller at different distances from the cam. Current was obtained from four storage cells having a capacity of 50 ampère-hours; it was found that to obtain regular ignition the spark must be short and thick, any smaller number of cells did not in all cases produce ignition. The results have been most excellent; the ignitor has been in use without repair for more than two years, and has never been seen to fail to fire the charge. As compared

Electric Firing Gear.

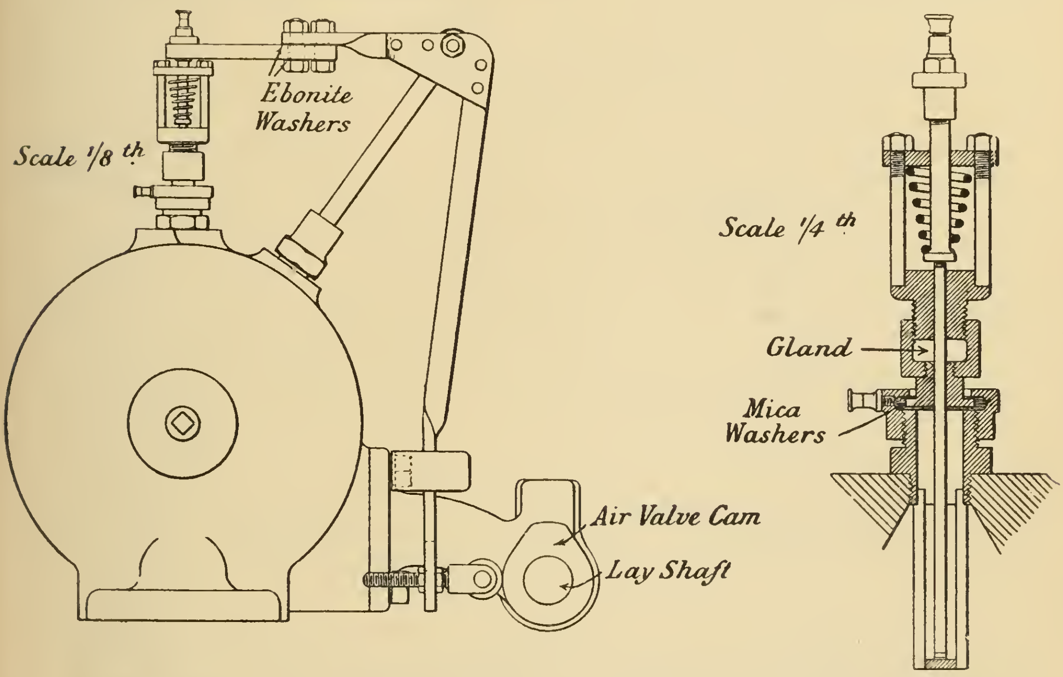


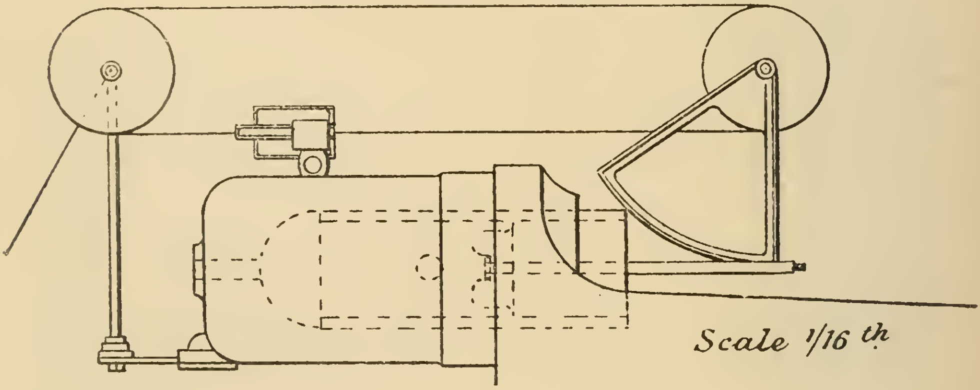
Fig. 1.—*End Elevation.*

Fig. 2.—*Section.*

with the hot tube, it has many advantages from an experimental point of view; and by means of the spark, charges which are so weak as to give irregular results with the hot tube, can be ignited with absolute certainty.

Indicator.—The method of driving the steel wires which are attached to the indicator, Fig. 3, has been slightly altered from the form that was first used, in order to obviate the necessity for correcting diagrams for the unequal multiplication of the driving gear. The swinging shaft was driven by the sector of a circle, which was keyed on to the shaft. The sector was connected to the piston by means of steel tapes which were kept at constant tension, in order to prevent any loss of motion. The sector is shown in Figs. 4 and 5.

Fig. 3.—*Indicator Driving Gear.*



Exhaust-Gases.—The same form of apparatus for the collection of exhaust-gases was used as described in the First Report. To remove any question of air being sucked in from the small valve at the back of the collecting tube, the valve was removed, and the tube connected to a water pump was attached inside.* During the tests, the water pump was kept working, which drew a considerable volume of the exhaust-gas past the collecting valve. The gases were analysed in a gas apparatus, which was also used for the analysis of the coal gas.

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* Proceedings 1898, Fig. 19, Plate 55.

The Tests.—The system which was followed in making the experiments was to work on four compressions: these are lettered A compression about 55 lbs. per square inch (App. II), B compression about 71 lbs. per square inch (App. III), C compression about 93 (App. IV), and D compression 124 lbs. per square inch (App. V), the pressures being absolute. The speed was kept the same for the whole of the tests, that is, about 200 revolutions per minute; in all cases the load on the brake was adjusted so as to make the number of explosions missed as small as possible. Experiments on gas-engines, when a considerable number of explosions are missed, give rise to such varying ratios of air to gas as to render them useless from a research point of view; this is due to the fact that, when a blank charge of air is drawn in, the residue in the clearance space is more than usually diluted with air, and the indicator diagram following the blank charge is not the same shape as those which follow an explosion. The tests under any of the compressions are denoted by numbers, and are given in the order of the ratio of air to gas; a series starts with very nearly the theoretical amount of air which is required to burn the gas, and then the tests are separated by changes roughly of one per cent. in the carbonic acid as found in the exhaust gases.

Sector.
Fig. 4.—*Elevation.*

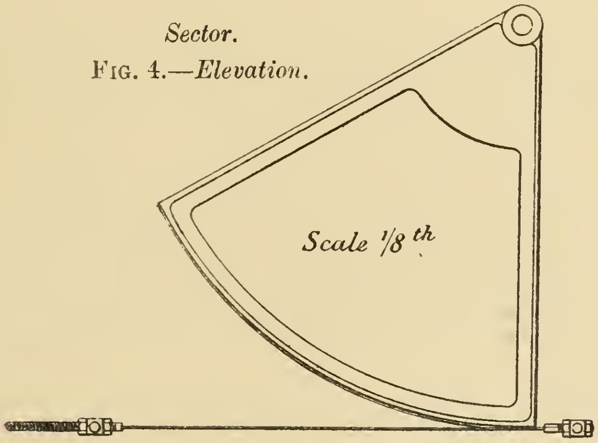
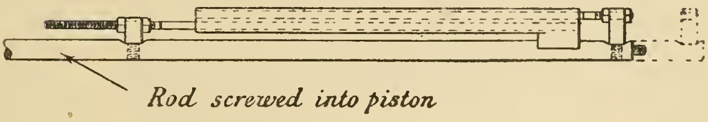


Fig. 5.
Plan.



All volumes, both air and gas, have been reduced to standard conditions, that is, a temperature of 15° C. and a pressure of 760 mm. of mercury; results are given in the metric system, but for the convenience of comparison a few leading figures have been given in the English units also; limits of space prevent the adoption of the dual system throughout.

The ratio of air to gas has generally been found by assuming that at the end of the suction stroke the cylinder is filled with only air and gas; if the temperature of the mixture be assumed, the volume of air can be calculated from the ordinary gaseous laws.

This method is certainly not correct, as there is always in the clearance space a volume of the products of combustion which have been left over from the previous explosion stroke; the temperature of the mixed air and gas has been generally taken as not differing greatly from the jacket temperature, an assumption which is not in general borne out by the present experiments. If an accurate analysis of the exhaust gases can be made, it is possible to find the ratio of air to gas in a somewhat similar manner as in boiler tests, where the weight of air per pound of coal is found from the analyses of the flue gases and coal.

The following quantities can be determined from the analysis of the coal gas:—

$K =$ the least number of volumes of air required to burn completely one volume of coal gas.

$l =$ number of volumes of carbon dioxide produced by the combustion.

$k =$ the volume after combustion of K volumes of air and one volume of gas.

Let N be the ratio of air to gas at the end of the suction stroke, y and z the percentages of carbon dioxide and oxygen in the exhaust gas. For one volume of gas there will be an excess of air of $N - K$ volumes, which is not required for the combustion of the gas, and which passes out to exhaust unaltered; after the combustion is finished, the volume of the burnt products will be k volumes; hence one volume of coal gas and N volumes in the cylinder will in the exhaust pipe have a volume of $N - K + k$.

As the percentage of oxygen in air is 0·209, there are two equations for finding the value of N—

$$y = \frac{l}{N - K + k} \qquad z = \frac{0 \cdot 209\,(N - K)}{N - K + k}$$

In this manner two values of N have been calculated, and are given in Tables 7; the results should agree, and such differences as exist are due to the experimentally determined constants K, k and l, which have to be obtained in a somewhat indirect manner, rendering them liable to error.

The ratio of air to gas used in the calculations is the mean between the two.

The measurement of the air drawn in during the suction stroke renders it possible to calculate the temperature at the end of the suction stroke.

Let V = volume of cylinder.

Vr = volume of clearance.

Va = volume of air drawn in per stroke reduced to standard conditions of temperature and pressure, which are 15° C. and 760 mm. of mercury.

Vg = volume of gas drawn in per stroke under the same conditions of pressure and temperature.

After the exhaust valve closes and a new stroke is about to commence, the clearance space is filled with air and burnt products, the composition of which is known from the analysis of the exhaust gases, and if the volume of this residue can be found, the temperature can be obtained by calculation.

The amount of air in the cylinder is NVg, this quantity being made up of two parts; first, the air drawn in Va, and second, the air left in the clearance space, which is $NVg - Va$ when reduced to standard conditions.

The fraction of air in the exhaust is known from the analysis of the exhaust gases; let it be n, then the total volume of air and products of combustion in the clearance space when the suction stroke is about to commence is clearly $\frac{NVg + Va}{n}$; during the suction stroke an additional volume of air and gas, $Va + Vg$, is drawn in, so that the total volume in the cylinder at the end of the suction stroke is $V\left[\frac{g-a}{n}+a+g\right]$ when reduced to a temperature of 15° C. and a pressure of 760 mm. of mercury.

If T be the absolute temperature of the mixture, and P the pressure in millimètres of mercury, which is found from the pumping diagrams, T can be found from the ordinary gaseous laws, as the volume is known to be $V(1+r)$, that is—

$$\frac{760\, V\left[\frac{g-a}{n}+g+a\right]}{273+15}=\frac{PV(1+r)}{T}$$

that is,

$$T=\frac{288\, P\,(1+r)}{760\left[\frac{g+a}{n}+g+a\right]}$$

The temperatures obtained in this way are shown plotted in Plate 182, and from the nature of the calculation the values must be looked upon as only approximate, when the charge is rich; that is when $NVg-Va$ is small any error will greatly affect the value of T.

The values of the suction temperatures used in forming a heat balance have been obtained by drawing a mean line through the temperature points when plotted on a base of the ratio air to gas.

The indicated power has been derived from the net mean pressure on the piston, that is, subtracting from the gross mean pressure as measured the average mean pressure during suction and exhaust. Although the missed explosions were only a small fraction of the whole, it was considered advisable to correct for the increased size of diagram which follows after a missed explosion; such diagrams were allowed that weight in the whole number of diagrams which corresponded with the number of missed explosions. The suction diagrams for tests A B and D are shown in Plate 183.

The reporter would have preferred to derive the indicated power from the gross mean pressure, and to consider suction and back pressure as forming part of the mechanical losses; the case of a steam-engine, in which the auxiliary pumps are driven from the main engine, would support this contention. Having the temperatures of suction, it is a simple matter to calculate the temperatures at any other point from the known pressures and volumes, such temperatures being the mean temperatures throughout the cylinder; in another portion of this Report (page 1055) it will be shown that there is reason to suppose that the temperature throughout the cylinder is not uniform, but that the core may be hotter than the mean. The highest calculated mean temperature is nearly 2,000° C., and it is possible that the core is hotter even than this; most authorities have considered 1,600° C. as the upper limit, but the reporter is of opinion that this temperature is too low.

In finding the additions of heat both at constant volume and constant pressure, and in finding the changes of internal energy, it is necessary to know the specific heat of the burning mixture, which consists of nitrogen, carbonic acid, oxygen, and water vapour. The reporter has consulted most of the original memoirs dealing with this subject, and decided to adopt the values obtained from the experiments of MM. Mallard and Le Chatelier on the specific heat at high temperatures; their investigations show that the specific heat is not constant as had been supposed by the older savants, but increases with the temperature according to the following formulæ:—

The values* are for specific heat at constant volume at temperature t:—

Carbon dioxide . . .	$0\cdot1477 + 0\cdot000176\,t$
Water vapour . . .	$0\cdot3211 + 0\cdot000219\,t$
Nitrogen	$0\cdot170 + 0\cdot0000872\,t$
Oxygen	$0\cdot1488 + 0\cdot0000763\,t$

These results are not in agreement with those obtained at low temperatures, nor do they agree with Dr. Jolly's researches by means of the steam calorimeter, but for temperatures such as are found in gas-engines they form the only available experiments.

The values of the specific heat for different mixtures of air and gas are given in Tables 7 and shown in Plate 182.

The variable specific heat considerably changes the formulæ employed, and as no English work, to the reporter's knowledge, contains an account of the theory of the gas-engine with variable specific heat, the formulæ are given here, the units being metric.

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* Comptes Rendus, 1887, vol. civ, p. 1780.

Let T_1 be the absolute temperature at the end of compression, T_2 the absolute temperature at the end of constant volume, T_3 the absolute temperature at the end of constant pressure, and T_4 the absolute temperature at exhaust, w_1 the known weight of air and gas, w_2 the weight of residual products left from the previous stroke in the clearance space, this latter quantity being obtained by calculation from the known suction temperature.

$$\text{Specific heat at constant volume} = a + sT$$

$$\text{Specific heat at constant pressure} = b + sT$$

Then heat added from end of compression to end of constant volume—

$$= (w_1 + w_2) \int_{T_1}^{T_2} (a + sT)\,\delta T$$

$$= (w_1 + w_2) \left[a\,(T_2 - T_1) + \frac{s}{2}(T_2^2 - T_1^2)\right]$$

Heat added from end of constant volume to end of constant pressure—

$$= (w_1 + w_2) \int_{T_2}^{T_3} (b + sT)\,\delta T$$

$$= (w_1 + w_2) \left[b\,(T_3 - T_2) + \frac{s}{2}(T_3^2 - T_2^2)\right]$$

The expansion period is perhaps the most interesting point in connection with the gas-engine; if the constant specific heat be adopted, it will be found that during expansion, instead of heat being lost to the walls as would have been expected, there is an apparent gain of heat by the charge which has been named after-burning. If the hypothesis of a variable specific heat be adopted, it will be found that in almost all cases there is heat lost to walls, and that combustion is complete at the point of maximum temperature. To determine this an adiabatic curve is drawn through the point of maximum temperature and continued to the same volume as exhaust.

The equation to an adiabatic is not the same as with the ordinary specific heat, and, with the same notation as before, is obtained thus:—

If an amount of heat δq be added, we have—

$$\delta q = K_v \left(\frac{dT}{dp}\right) \delta p + K_p \left(\frac{dT}{dv}\right) \delta v,$$

and

$$\frac{dT}{dp} = \frac{v}{R} \quad \frac{dT}{dv} = \frac{p}{R},$$

hence

$$\delta q = K_v \frac{v}{R} \delta p + K_p \frac{p}{R} \delta v$$

for an adiabatic $\delta q = 0$, and—

$$(a + sT)\, vdp + (b + sT)\, pdv = 0,$$

or

$$avdp + bpdv + s\,\frac{pv}{R}\,(vdp + pdv) = 0.$$

The integral of this is—

$$(b - a) \log_e v + a \log_e (pv) + s\,\frac{pv}{R} = \text{constant},$$

$$\text{or } p^a\, v^b\, e^{s\frac{pv}{R}} = \text{constant}.$$

where e is the Naperian base and $R = K_p - K_v = b - a$.

The adiabatic curves both on a constant specific heat assumption and a variable specific heat assumption are shown in test B_2, Plates 177 and 184.

From this equation the temperatures at the end of adiabatic expansion have been calculated, and are given in Tables 11. A comparison with Tables 4 will show that, except for the very weak charges, the exhaust temperatures are much the lower; in C_8 the condition is reversed, the exhaust temperature being 45° C. above the temperature on the adiabatic; and it will be seen that the thermal efficiency has fallen by nearly 2 per cent.; the same is shown in D_9 and D_{10}, while in D_8 the temperatures are nearly the same, the thermal efficiency being then a maximum. These experiments would tend to prove that for maximum economy the expansion should be nearly an adiabatic. Thermo-dynamics show that for maximum economy all the heat should be added at maximum temperature, and that any after-burning is detrimental.

In finding the heat discharged to exhaust, it has been general to estimate the heat as the change of internal energy of the whole weight of the charge, in cooling from the temperature of exhaust to the temperature at the end of the suction stroke; part of this energy only passes out, the remainder being supposed to be given to the jacket.

In the heat account for these tests the heat rejected to exhaust has been divided into two parts: first, the heat energy of the total weight of air and gas taken in, the products of combustion being cooled down to atmospheric temperature: second, that part of the charge which does not pass out of the cylinder, but remains in the clearance space to mix with the air and gas of the next stroke.

Some of the heat energy however does pass out, being converted into kinetic energy of the exhaust. To estimate this amount, the charge in the clearance space has been supposed to expand adiabatically from exhaust pressure to the pressure of atmosphere; the change of internal energy due to this expansion has been taken as the heat lost by the residue to exhaust.

The amount of heat thus determined is not large, forming about 3 per cent. of the total heat; the amount of the products of combustion in the clearance space varies of course with the compression and with the suction temperature; for the A tests of the whole weight of charge about 25 per cent. is residue, for B tests 16 per cent., for C tests about 15 per cent., and for the D tests about 8·5 per cent.

In forming a heat balance by the two methods, there will not be a great difference between the internal energy at exhaust and heat energy of the incoming air and gas when cooled from exhaust temperature to atmospheric temperature, when the compression is high, as then the influence of the clearance residue is small; but for low compressions, such as in test A, there is a marked difference between the two; if any method of finding the heat rejected to exhaust is correct and leads to a fairly accurate heat balance, it must apply to all cases. The figures are given for thirty-eight tests under very varied conditions, and the heat balances are as good as can be expected for such a complex problem.

In Dr. Slaby's experiments a slightly larger engine was used with a slide-valve and a low compression; the best thermal efficiency was about 16 per cent. and the loss to exhaust nearly the same as in the reporter's experiments.

The loss to the jacket was much larger than in the reporter's tests, and modern gas-engines owe their improved efficiency mainly to a reduced wall loss.

The effect of a scavenger charge may be inferred from the relative weights of the incoming charge and the clearance residue; if the latter can be expelled, a larger total volume of charge can be drawn without greatly increasing the jacket loss, but the gain diminishes as the compression is increased.

For many reasons very high compressions are not desirable, and the reporter wishes to draw attention to the fact that at present gas-engines are only utilising about one-third of their total temperature range, when working under best conditions, while in steam-engines more than three-quarters of the temperature range is utilised.

The additions of heat of various portions of the stroke have been worked out, and an example from each of the four compressions is given in Appendix VI (page 1082); want of space has prevented the results being given in full.

The heat additions give a check on the heat balance, and the results for the whole of the tests are in fair agreement. Had the specific heat of the charge been taken as constant in the calculations, the results would have been about 15 per cent. smaller.

The values taken for the heating values of the gas in Tables 1 and 2, Appendix I (page 1057), are those of Dr. Slaby, and in each case the latent heat of the water formed by combustion has been deducted. As to which of the two values are to be used for the calorific value of a gas, all authorities are not agreed. If the heating value of a gas be determined by burning in a calorimeter such as the Junkers, the result will be the higher, because the products of combustion have been cooled to nearly atmospheric temperature. From a logical point of view the heating value of a gas should be taken as the heat given out, when the products of combustion are cooled down to the original temperature of the incoming air and gas; this includes as part of the heating value of the gas the latent heat of the water vapour, which is produced by the combustion of hydrocarbons; in an average coal gas the latent heat of the water vapour amounts to nearly 10 per cent. of the gross heat as measured in the calorimeter. The justification for adopting the lower number for the calorific value is that in all practical applications of gas, whether in a gas-engine or in a furnace, it is almost impossible to conceive any arrangement by which the water vapour could be rejected as water, and not, as is always the case, in the form of steam. It has generally been the custom, both in this country and in Germany, to use the lower value, and as it is most desirable that there should be a uniform standard, the Gas-Engine Research Committee and the reporter suggest the use of the lower value as being a measure of the available heat of the gas, whereas the higher value is not a practical standard of the heat which can be utilised outside a calorimeter.

The additions of heat during the various parts of the cycle may be studied by means of the entropy diagram, but, as fresh diagrams have to be drawn for each test, it is questionable if the result is worth the very considerable labour that is involved. The general formulae for constructing the entropy diagram are now given, so that diagrams may be constructed if required.

Let ϕ be the change of entropy when one kilogramme of the mixture changes its temperature from T_0 to T_1. With the specific heats as before $K_v = a + sT$, $K_p = b + sT$, and $R = b - a$; then $\phi = a \log_e \frac{T}{T_0} + R \log_e \frac{V}{V_0} + S(T - T_0)$, where V and V_0 are the volumes at temperatures T and T_0 respectively. The diagrams are constructed by drawing a series of lines along which the pressure is constant, and a second series along which the volume is constant.

The indicator diagram can then be plotted from the known pressures, and by dividing the actual volume of the charge by its weight in kilogrammes.

The zero is best taken at 0° C., that is $T_0 = 273°$ C.; if the temperatures are plotted vertically and the entropies horizontally, it is best to plot constant volume and constant pressures and constant volume lines at intervals of every 50° C. starting from the line of zero entropy. To find the actual pressures and volumes for these lines, let a line start from the line of zero entropy at a temperature T_1, pressure P_1, volume V_1.

Then
$$R \log_e \frac{V_0}{V_1} = a \log_e \frac{T_1}{T_0} + S(T_1 - T_0)$$
and
$$R \log_e \frac{P_1}{P_0} = b \log_e \frac{T_0}{T_0} + s(T_1 - T_0),$$
this fixes V_1 and P_1 in terms of T_1.

The principal use of the entropy diagram would be in comparing an actual engine with a perfect gas-engine working under the same conditions. In the case of steam the Rankine cycle has been adopted, and for gas-engines several cycles have been proposed. The reporter has investigated the question, but is at present unable to recommend any particular cycle as being best adapted for actual engine comparison.

Coal Gas.—In the ordinary analysis of a coal gas there exists some difficulty as to the exact composition of the compound, which is absorbed by the fuming sulphuric acid. It is a mixture of the higher hydro-carbons, and is generally taken as having a composition of $C_3 H_6$. Although the percentage of this hydro-carbon is small, being only about 5 per cent. by volume, yet owing to its high heating value it forms a considerable factor in the heating value of the coal gas. A brief account of the method employed to determine the composition of this hydro-carbon is all that is necessary. In addition to exploding the marsh gas and hydrogen alone, an explosion was made of the coal gas mixed with the air simply. From the data thus obtained, it was possible to find the values of m and n, if the hydro-carbon were taken as $C_m H_n$. The values obtained were not integral, which means that a number of the higher hydro-carbons were mixed together. The analysis and data of the average coal gas is shown in Appendix 1 (page 1057). Dr. Slaby has shown* that the heating value of hydro-carbons can be represented by the formula—heating value $= 1000 + 10500\,d$, where d is the density of the gas, the units being in calories and cubic mètres.

Radiation.—The heat, which is rejected into the jacket-water, will of course be slightly less than the heat which is passed through a cylinder wall, due to the fact that some of the heat is radiated from the outer surface of the cylinder into the air. Although this amount was comparatively small, it was deemed advisable to make a special experiment in order to determine its amount. After the jacket had been raised to the required temperature, the engine was stopped and a measured supply of hot water allowed to pass through the jacket; the temperatures of this water both at the inlet and the outlet were measured. The radiation can then be determined from the difference of these temperatures together with the known weight of water. [The results are given on page 1088.]

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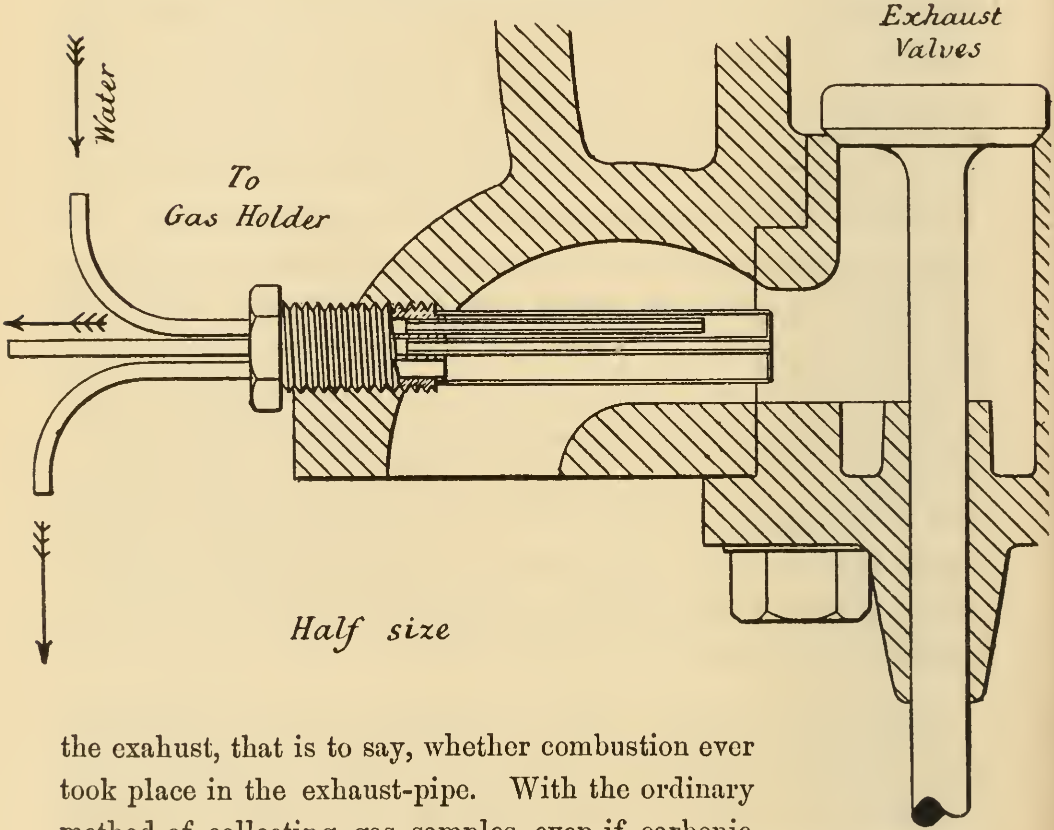
* Calorimetrische Untersuchungen über den Kreis-progress der Gas Machine, page 6.

Test of Carbonic Oxide.—A series of experiments were made, in order to determine if it were possible for carbonic oxide to exist in the exahust, that is to say, whether combustion ever took place in the exhaust-pipe. With the ordinary method of collecting gas samples, even if carbonic oxide existed, it would not be found in the analysis, because it would recombine with the free oxygen and form carbonic acid before being corrected. To prevent any possible burning of the carbonic oxide in the exhaust-pipe, a collecting tube was water-jacketed through its entire length, and a stream of cold water passed rapidly through its jacket, Fig. 6. This would cool down the exhaust gases so rapidly as to prevent burning of carbonic oxide to carbonic acid, if

Fig. 6.—*Exhaust-Gas Sampler.*



not entirely, at any rate to a large extent. The engine was run with a very late ignition and with rich charges, so that the conditions for the formation of carbonic oxide in the exhaust were most favourable. In no case however could the smallest trace of carbonic oxide be discovered, although, had there been as little as $\frac{1}{10}$th part of 1 per cent. it would have been detected.

The Temperature Tests.

One of the principal objects which the Research Committee had in view was the determination of the temperatures at all points of the Otto cycle, by means of a direct measurement in place of by the usual indirect method of calculation. The reporter made a series of experiments on the measurement of cyclically varying temperature, and the results were published in the Philosophical Magazine for September 1895; but for the sake of completeness and in order to make clear some of the methods of working, it has been thought advisable to give a full account of the temperature measurements even at the risk of some repetition. Among the many methods that have been employed for the practical measurement of temperature is that method which depends upon the change of electrical resistance in a metal conductor, due to the change of the temperature. This electrical resistance method seems to have been used by Sir William Siemens with rather unsatisfactory results, due mainly to the defective construction and to imperfect apparatus for measuring the changes of resistance. The method has, however, always had a great fascination for physicists, owing to the ease and great accuracy with which resistance measurements can be made.

The credit of constructing accurate and practical resistance thermometers is due to Professor H. L. Callendar, F.R.S., who compared the readings of a platinum thermometer with that of an air thermometer up to about 600° C.,* and he then showed that with proper precautions temperatures could be measured with a precision nearly impossible by any other thermometer. For temperatures above 600° C. no direct comparison of the platinum and air scales has as yet been made, mainly owing to the almost insuperable difficulties which air thermometers present when used at high temperature. Much indirect evidence has been accumulated, and strengthens the belief in the accuracy of Callendar's formula, even when exterpolated beyond the range of his own experiments. If the resistance of a piece of platinum is measured both in melting ice and in steam boiling under a pressure of 760 mm. of mercury and the resistances be R_0 and R_1 respectively, and if R be the resistance at any other temperature, then the platinum temperature $p_t = \frac{R - R_0}{R_1 - R_0}$ is defined in the same manner as a degree in the mercury scale. There still remains the connection to be applied, because the temperature on the air scale and the platinum scale are not the same. The difference between the two scales is expressed by the formula $t - pt = D\left(\frac{t^2}{100^2} - \frac{t}{100}\right)$, where t is the temperature on the air scale and the D a constant.

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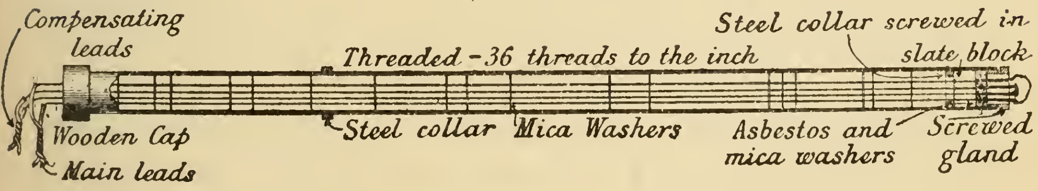
* Royal Society, Philosophical Transactions 1887, page 8.

To find D, the thermometer is calibrated by measuring its resistance at a very high temperature, generally the boiling point of sulphur being chosen, as it is one of the highest boiling points which has been accurately determined.

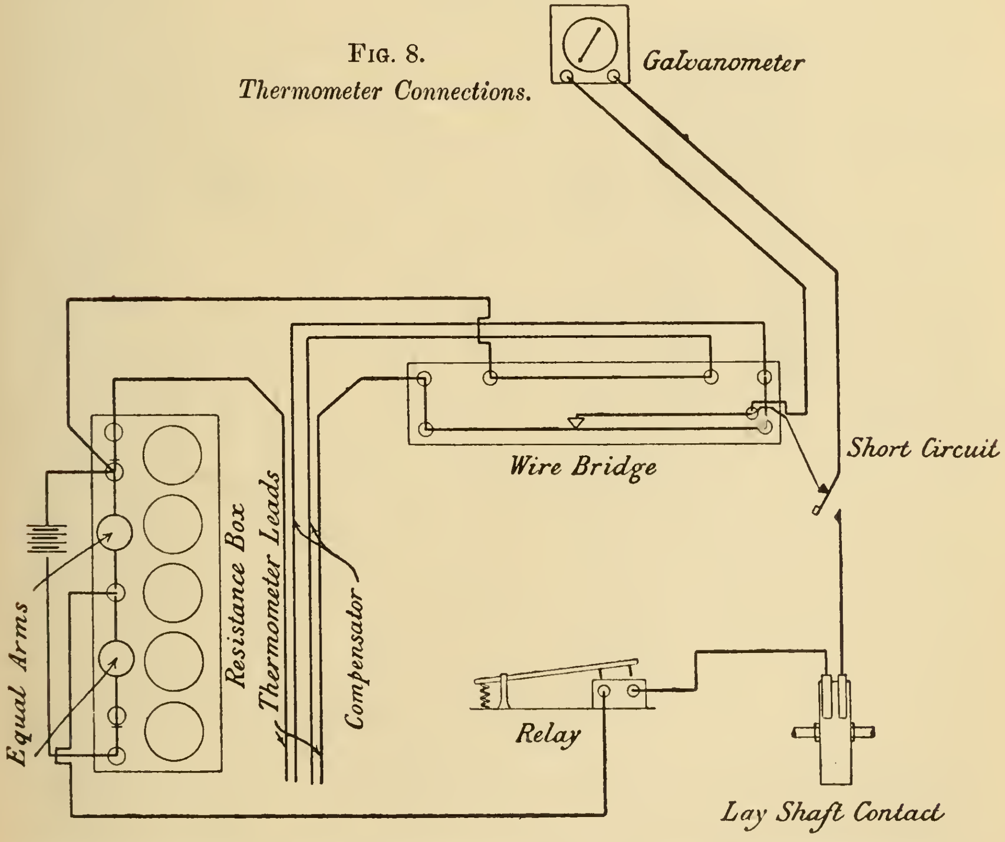
The value of D ranges from 1·3 to 1·5 according to the purity of the platinum wire; different samples of platinum wire will not in general give the same platinum temperature when placed in the same source of heat; but when the correction to the air scale is applied, the two wires will generally be found to agree. This remarkable consistency of the platinum thermometer is one of the greatest points in its favour, and it is not unreasonable to suppose that its consistency is real. The construction of the ordinary platinum thermometer does not fall within the scope of the present Paper, but it may be generally described as a coil of platinum wire wound on a mica cross, the ends of the wire being soldered on stout platinum leads. A pair of dummy leads generally called compensators are provided to cancel the heating up of the main leads; the whole of the wires are enclosed in a porcelain tube, to protect the wire from possible injury which might result from the nature of the heating. When the reporter commenced the research to determine the temperatures reached in the gas-engine, it seemed as if the best method to employ was that of the electrical thermometer in a modified form. The difficulties were considerable, as not only were the temperatures to be measured very high, but the pressure which such a thermometer had to withstand was also great, and the total duration of the temperature not more than $\frac{1}{3}$ of a second. If it were required to measure the temperature at different points of a stroke, it became clear that the measuring wire must possess a very small thermal capacity. A very small thermal capacity necessitated the abolition of any covering to the wire. At first it seemed probable that to expose a very fine wire to the erosive influence of the burning gas would be likely to lead to inaccuracy in the measurements. Such, however, has not been found to be the case. The change of resistance of a wire when it has been exposed to several hundreds of explosions is almost too small to be measured. The form of the thermometer finally selected is shown in Fig. 7.

Fig. 7.—*Section of Pyrometer.*


Compensating leads
Threaded-36 threads to the inch
Steel collar screwed in slate block
Wooden Cap
Main leads
Steel collar
Mica Washers
Asbestos and mica washers
Screwed gland

It consists of a solid-drawn steel tube about 1 inch in diameter and 18 inches in length, the thickness being about $\frac{1}{20}$ of an inch. The outside of the tube is threaded from end to end, and has upon it a pair of nuts. This allows the measuring wire to be placed at any distance from the wall of the cylinder, the nuts also serving to hold the thermometer in position by means of an ordinary screwed gland packed with asbestos. The inside of one end of the tube is bored out for a short distance, and internally threaded. A circular slate block fits into the bored-out portion of the tube. The four leads which are of platinum pass through the holes in the slate block; to prevent the leads being blown out of the tube by the pressure, each lead is provided with a small platinum collar which bears against the outside of the slate block. The whole is made gas-tight by means of alternate layers of asbestos and mica, which are forced down by a screwed gland. This construction packs itself by the pressure, and no trouble has been experienced from the gas leaking through the slate block. The leads are insulated from each other and from the iron tube by mica washers at short intervals. The leads terminate in an ebonite head fastened to the outer end of the steel tube, and provided with suitable terminals for attachment to the measuring apparatus. This form of thermometer has been in use for its special purpose for a number of years, and has been found to stand at the same time high temperatures and pressures exceeding 200 pounds per square inch. Moisture by wetting the asbestos destroys the insulation, and therefore in finding the resistance in ice and steam the thermometer was protected from direct contact with moisture by a thin copper tube. The general principle used in measuring the temperature was to cause the engine itself to complete the galvanometer circuit at the particular point of the stroke at which the temperature was required to be measured. This would be a simple matter with a steam-engine, as all that would be necessary would be a circuit measure placed on the shaft. With a gas-engine an explosion can occur at most but once in two revolutions, hence some means must be devised whereby the circuit shall be closed not only at the definite point in the stroke, but also only when an explosion has taken place. Moreover as the size of the measuring wire must of necessity be very small, ranging from 0·0025 to 0·0015 inch, it becomes of the highest importance to expose the wire to the high temperature for as small a number of explosions as possible. All attempts to use these measuring wires, with an engine firing every second revolution, have resulted in the destruction of the wire before a sufficient number of observations could be taken. The temperatures have therefore been measured on an engine running dead light; that is, firing about one in six of the possible explosions. There is also the difficulty of ensuring that the wire follows the temperature of the gas during expansion. This can be done, provided the gas-engine does not run at a speed much exceeding 120 revolutions per minute. The arrangement of contact-makers is shown in Fig. 8. The galvanometer circuit was broken in two places, one of which was completed during every working stroke and the other at a definite point in each revolution. Thus readings of the galvanometer can only be obtained at the particular point of the working stroke for which the mechanism is set. The contact-maker called a relay is arranged to close the galvanometer circuit by the movement of the gas admission valve, at the commencement of the suction stroke; when the electro-magnet is excited the lever is depressed and the galvanometer circuit closed by means of two mercury cups. To prevent the lever lifting before the working stroke is over, it is arranged that when the lever has moved through a small distance the break on the gas lever is short-circuited by a third mercury cup, the relay circuit remaining closed until broken by a contact on the exhaust valve on the engine. This arrangement ensures the closing of the galvanometer circuit

Fig. 8.
Thermometer Connections.



from the commencement of the suction stroke until the exhaust valve opens. Two forms of contact-makers for fixing the point of the stroke at which the temperature has to be measured were employed; the first was used in the tests marked from X to Y. It was then replaced by the one shown in Figs. 9 and 10, which consists of a wooden disc attached to the lay shaft; let into its circumference is a small brass block; bearing on this block are two copper springs, which are arranged so that they can be set in a required position. To make a determination of the temperature, all that is required is to set the lay shaft contact-maker to the required point in the stroke, the resistance measuring apparatus must then be adjusted until the swings on the galvanometer circuit can be read. As the temperatures vary slightly from stroke to stroke, it is impossible to get an accurate balance. The method employed was to put such a resistance into the resistance box that the galvanometer would throw constantly to one side. Ten readings were made of the

Contact Maker.

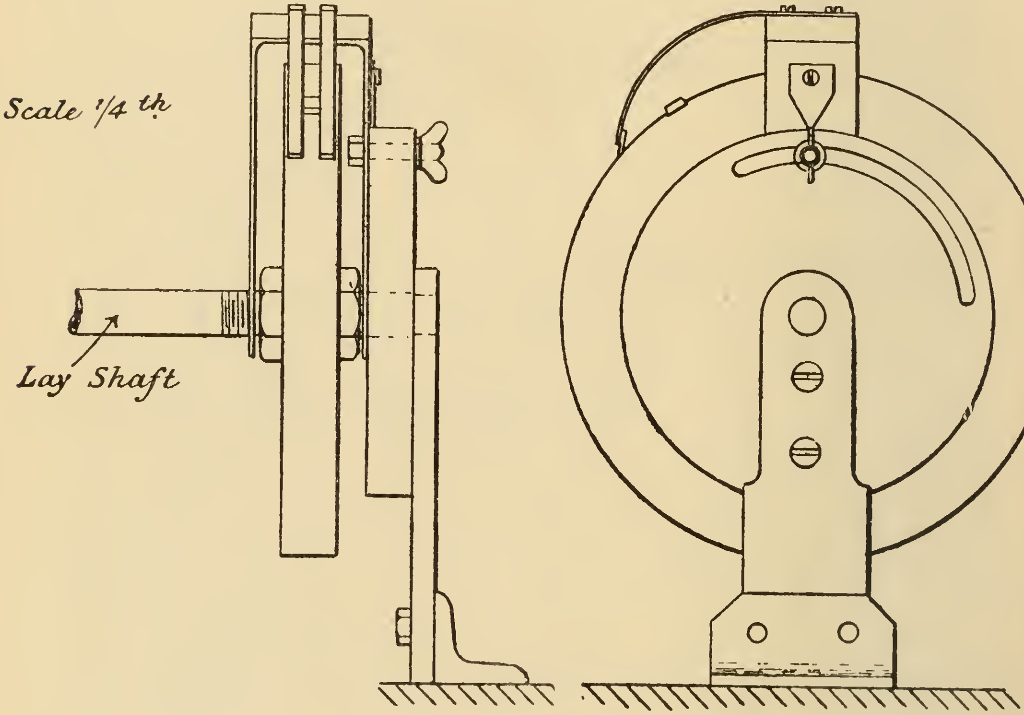


Fig. 9.

Fig. 10.

galvanometer throws, and then a second resistance put into the resistance box of such a magnitude, that the galvanometer throws are all on the opposite side to that of the previous determination. Ten throws were again observed, and the resistance interpolated from the mean of these readings, thus each observed temperature was found from observing the temperatures of twenty explosions. The resistance measuring apparatus consisted of an ordinary wire bridge and a resistance box, Fig. 8 (page 1051). The galvanometer was a Crompton d'Arsonval. The testing current was supplied by a secondary cell with an added resistance of about 50 ohms. The results of a number of experiments are shown in the three Tables (pages 1084–6). In those headed X the measuring wire had a diameter of 0·0025; in Y of 0·002, and in Z of 0·0015 (Plates 180 and 181). The length of the measuring wire was about $\frac{3}{4}$ inch, the compensators being joined by a small length of about $\frac{1}{4}$ inch. Repeated attempts were made with wires having a diameter of 0·001 inch, but the wire was always fused after a very few explosions. In Plates 180 and 181 the full line is a line drawn through the actual observed points, while the dotted line is the line obtained by assuming that at some fraction of the stroke the thermometer has actually reached the exact temperature of the charge. In the case of the X tests the fraction is 0·3, for Y tests 0·5, and Z tests 0·6 of the stroke. As will be expected, the lines show that for the first $\frac{2}{10}$ stroke the wire is probably reading too low, at any rate with the thickest wire; towards the latter end of the stroke with the finer wires the coincidence between the measured temperature and that obtained by calculation on the ordinary gaseous laws are remarkably close, and lead to the belief that during expansion the charge behaves approximately as a perfect gas. In addition to measuring the temperatures during the explosions-stroke the suction temperature was also measured; having now both the pressure P, volume V, temperature T, at the end of the suction-stroke and also at various points on the expansion curve, it is possible to calculate the product $\frac{P\,V}{T}$ both before and after explosion, Appendix IX, (page 1087). This was done, with the result that, assuming that the suction temperatures were correct, the measured temperatures during expansion were very much too high. This is found in the whole of the tests and is more strongly marked with the very fine wire. With a view of checking the way in which the wire followed the temperature, the temperatures were measured from beginning to the end of compression, and the results are shown on the Table; they prove that the wire actually followed the temperature with a very reasonable degree of accuracy. It is also conjectured that, as the indicator diagrams were taken with the indicator open while the temperatures were measured with the indicator shut, perhaps the leak through the indicator was sufficient to account for the higher temperature as shown by the thermometer. An experiment was made with the indicator open and shut, with the result that the indicator open showed a slightly higher temperature.

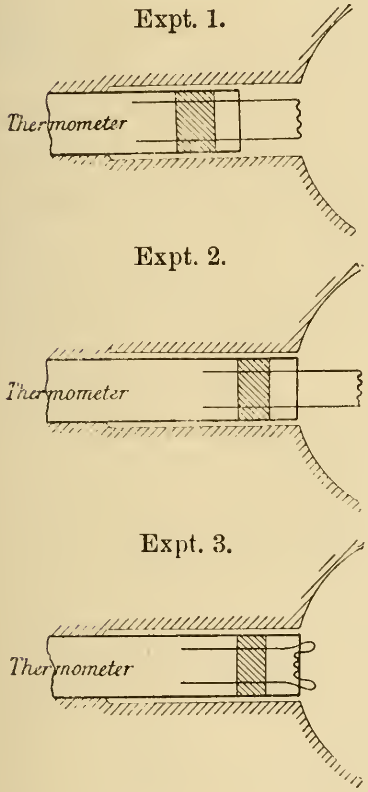
It occurred to the reporter that possibly the discrepancy might be accounted for on the hypothesis that the temperature throughout the cylinder was not uniform. All the temperatures were measured on wire almost in the centre clearance space, which naturally would be the hottest part. The calculated temperatures are of course the mean of the whole temperature throughout the cylinder.

Three experiments, Fig. 11 (page 1055), were made with the measuring wire in different positions, the first case on a level with the inner wall, in the second case standing out some ½ inch, and in the third case with the measuring wire bent back as near as possible to the steel body of the thermometer so as to imitate the cooling action of the wall. The temperatures thus obtained show a very decided falling off as the wire is brought closer to the wall, amounting in one case to nearly 200° C.

Doubtless the wall action in the case of a very low speed of some 90 revolutions per minute would be much more marked than at the ordinary speed of 200 revolutions per minute, but the experiments prove that there is a comparatively wide range of temperature in the cylinder itself; if it were possible to place one of the measuring wires at 0·01 inch from the wall it is probable that even when the core was standing at some 1,300° C., the temperature at the wall might not exceed 800° or 900° C. The existence of even a thin layer of comparatively cold gas on all the clearance surfaces would be sufficient to reconcile the temperatures calculated by means of pressures, volumes and temperatures of exhaust with those observed, but until the law of variation of temperature throughout the cylinder has been determined, such a calculation would be of comparatively small value.

Mr. J. B. Wood has taken a very large share of the labour of both making the experiments and working out the results; the reporter wishes to express his thanks to Mr. Wood for his valuable assistance.

Fig. 11.—*Experiment showing variation of Temperature with Thermometers at different depths in Cylinder.*



	Temp. at $\frac{3}{10}$ of stroke.	Temp. at $\frac{8}{10}$ of stroke.
Expt. 1.	977° C.	714° C.
Expt. 2.	1,110° C.	765° C.
Expt. 3.	904° C.	624° C.

The experiments were made in the Engineering Laboratory of the University; the reporter desires also to thank the University for placing at his disposal suitable rooms for the work.

The Report is illustrated by Plates 176 to 184 and 11 Figs. in letterpress, and is accompanied by Appendices I. to IX.

LIST OF APPENDICES.

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,, IV. (,, 1070).—C ,, ,, ,,
,, V. (,, 1076).—D ,, ,, ,,
,, VI. (,, 1082).—Heat Additions, Calories per Explosion. Heat given to Jacket.
,, VII. (,, 1083).—Effect of Change of Compression (Lighting Gas).
,, VIII. (,, 1084).—Temperature of Charge during Expansion and Suction.
,, IX. (,, 1087).—Experiments on Firing the Charge at different percentages of Stroke, etc.

Metric Measures and British Equivalents.

1 mètre = 39·37043 inches.
1 kg. per cm^2. = 14·223 lbs. per square inch.
1 calorie = 3·968 British Thermal Units.
1 calorie = 3087 foot-lbs.
1 litre = 1·761 pints.
1 litre = 61·025 cubic inches.
1 kilogramme = 2·2046 lbs.
1 calorie per litre = 112·36 B.T.U. per cubic foot.

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1 cubic foot = 0·0283 cubic mètre.
1 ,, ,, = 28·3 litres.
1 lb. per square inch = 0·0703 kg. per cm^2.
1 British Thermal Unit = 0·252 calorie.

All temperatures are above zero.

APPENDIX I.

Table 1.

Analysis and Products of Combustion of Coal Gas by volume.

Mean of 8 Samples.

	Per cent.	Carbonic acid produced.	Oxygen required.	Steam produced.
Carbon Dioxide, CO_2 . . .	0·16	0·16	—	—
Heavy Hydrocarbons, $C_3H_{6\cdot7}$	4·48	13·43	20·93	15·0
Oxygen, O	0·13	—	—	—
Carbon Monoxide, CO . .	9·46	9·46	4·73	—
Marsh Gas, CH_4	33·67	33·67	67·34	67·34
Hydrogen, H	43·40	—	21·70	43·40
Nitrogen, N	8·70	—	—	—
Totals	100·00	56·72	114·70	125·74

One volume of coal gas requires 5·49 volumes of air, and produces 0·5672 volume of CO_2 and 1·257 volumes of steam. After combustion the volume dry is 4·996.

Weight of 1 cubic mètre of gas dry at 15° C. 760 mm. = 0·600 kg.
" " " air " " " = 1·290 "

Table 2.

Heating value of Coal Gas.

(*See page* 1043.)

The heating values are taken less the latent heat of water vapour, and are in calories.

	Per cent. by volume.	Heating value of one cubic mètre at 15° C. 760 mm.	Heating value of each constituent in one cubic mètre of coal gas.
CO_2	0·16	—	—
$C_3H_{6\cdot7}$	4·48	20,090* calories	900 calories
O	0·13	—	—
CO	9·46	2,878 "	272 "
CH_4	33·67	8,030 "	2,704 "
H	43·40	2,440 "	974 "
N	8·70	—	—
Totals	100·00	—	4,850 calories.

* Heating value of 1 cubic mètre of $C_3H_{6\cdot7}$ = 1000 + 10,500 d = 20,090
d = density being 1·912.

Heating value of 1 cubic mètre of coal gas = 4,850 cal.
" " 1 cubic foot " " = 553 B.T.U.

APPENDIX II.

A TRIALS. (Plate 176.)

Table 1.

Clearance vol. in litres.	Stroke vol. in litres.	Ratio : $\frac{\text{clear vol}}{\text{cylr. vol.}}$	Clearance surface in cm².		Approximate Compression. Absolute.	
			Total.	Jacketed.	Kg. per cm².	Lbs. per sq. inch.
3·146	5·522	0·57	1680	1200	3·88	55

Table 2.

Test No.	Revolutions per minute.	Explosions per minute.	Per cent. of Full Power.
1	191·5	95·7	100
2	190·3	94·4	99
3	200·6	96·2	96
4	201·5	95·7	95
5	207·5	89·9	87
6	197·1	94·3	96
7	206·8	99·2	96
8	201·3	91·7	91

Table 3.

Test No.	Suction Pressure.	Suction Temperature.	Compression.		n in $PV^n = \text{Const.}$
			Pressure.	Temperature.	
	Kg. per cm².	C.°	Kg. per cm².	C.°	
1	1·00	153	3·82	318	1·322
2	,,	140	3·75	290	1·303
3	,,	130	3·85	291	1·331
4	,,	121	3·98	286	1·363
5	,,	111	4·07	295	1·385
6	,,	102	3·67	227	1·284
7	,,	99	4·32	311	1·445
8	,,	85	3·67	204	1·284

A TRIALS—*continued.*

Table 4.

Test No.	Maximum Pressure.	Maximum Temperature.	Volume at Maximum Temperature.	Exhaust.		Mean Pressure, Gross.	n in PV^n = Const.
				Pressure.	Temperature.		
	Kg. per cm².	C.°	Litres.	Kg. per cm².	C.°	Kg. per cm².	
1	10·39	1751	3·97	3·22	1097	4·51	1·501
2	10·19	1594	3·85	3·04	982	4·20	1·491
3	10·10	1464	3·71	3·01	937	4·00	1·426
4	9·23	1394	3·98	3·10	947	3·92	1·400
5	8·78	1282	4·00	3·14	932	3·76	1·328
6	9·13	1269	3·91	2·99	847	3·82	1·405
7	7·35	1145	4·50	3·04	857	3·33	1·347
8	8·57	1119	3·93	2·82	737	3·50	1·410

Table 5.

Test No.	Explosions per minute.	Mean Pressure, Gross.		Correction for Suction.	Mean Pressure, Net.	I.H.P.		B.H.P.		Mechanical Efficiency.
						H.P.	Kw.	H.P.	Kw.	
		Lbs. per sq. in.	Kg. per cm².	Kg. per cm².	Kg. per cm².					
1	95·7	64·1	4·51	0·10	4·41	5·11	3·81	3·98	2·97	0·78
2	94·4	59·7	4·20	0·10	4·10	4·68	3·49	3·51	2·62	0·75
3	96·2	56·9	4·00	0·11	3·89	4·53	3·38	3·30	2·46	0·73
4	95·7	55·7	3·92	0·11	3·81	4·41	3·29	3·55	2·65	0·80
5	89·9	53·5	3·76	0·13	3·63	3·95	2·95	2·98	2·22	0·75
6	94·3	54·3	3·82	0·11	3·71	4·24	3·16	2·88	2·15	0·68
7	99·2	47·4	3·33	0·11	3·22	3·86	2·88	2·72	2·03	0·79
8	91·7	49·8	3·50	0·12	3·38	3·75	2·80	2·55	1·90	0·68

A TRIALS—*continued.*

Table 6.

Test No.	Gas per Explosion.	Air per Explosion.	Ratio Air to Gas.	Heating Value of Gas, Calories per litre.	Calorie per litre of Mixture.
	Litre.	Litres.			
1	0·686	3·76	5·5	4·993	0·768
2	0·610	3·93	6·4	4·993	0·675
3	0·561	4·03	7·2	4·993	0·609
4	0·540	4·25	7·8	4·864	0·553
5	0·510	4·20	8·2	4·864	0·529
6	0·527	4·28	8·1	4·993	0·549
7	0·450	4·52	10·1	4·864	0·438
8	0·493	4·24	8·6	4·993	0·520

Table 7.

Test No.	CO_2 per cent.	O per cent.	Ratio: $\frac{\text{air}}{\text{gas}}$ from CO_2.	Ratio: $\frac{\text{air}}{\text{gas}}$ from O.	Mean.	K_v.	$K_p - K_v$.
1	10·38	1·54	5·85	5·98	5·9	·1856+·000115 T	·0719
2	8·71	4·74	6·87	7·07	7·0	·1827+·000111 T	·0713
3	7·69	6·84	7·72	8·05	7·9	·1807+·000108 T	·0710
4	7·28	8·57	8·52	8·66	8·6	·1795+·000106 T	·0709
5	6·54	9·70	9·43	9·49	9·5	·1781+·000104 T	·0706
6	5·71	10·07	10·22	10·30	10·3	·1771+·000102 T	·0705
7	5·83	11·11	10·53	10·79	10·6	·1767+·000102 T	·0705
8	4·94	11·64	11·73	11·96	11·8	·1757+·000100 T	·0703

A TRIALS—*continued.*

Table 8.

Test No.	Gas per Hour.		Cub. ft. per I.H.P. per hour.	Cub. mètres per kilowatt-hour.	Cub. ft. per B.H.P. hour.	Cub. mètres per Brake kilowatt-hour.	Thermal Efficiency per I.H.P.
	Cub. ft.	M^3.					
1	139	3·94	27·2	1·03	35·0	1·33	16·6
2	122	3·45	26·1	0·99	34·8	1·32	17·4
3	114	3·23	25·3	0·96	34·7	1·32	17·9
4	110	3·11	24·9	0·95	30·9	1·17	18·7
5	98	2·77	24·8	0·94	32·8	1·25	18·7
6	105	2·97	24·8	0·94	36·5	1·39	18·3
7	95	2·69	24·6	0·93	34·9	1·32	18·9
8	96	2·72	25·6	0·97	37·6	1·43	17·7

Table 9.

Test No.	Weight of Air, per explosion.	Weight of Gas, per explosion.	Air+Gas, per explosion.	Air Temp.	Exhaust Temp.	Calories rejected to Exhaust, per explosion.
	Kg.	Kg.		C.°	C.°	Calories.
1	·00461	·000389	·004999	15	1097	1·35
2	·00482	·000346	·005166	,,	982	1·18
3	·00494	·000318	·005258	,,	937	1·13
4	·00521	·000307	·005517	,,	947	1·19
5	·00515	·000289	·005439	,,	932	1·13
6	·00525	·000299	·005549	,,	847	1·02
7	·00554	·000255	·005795	,,	857	1·08
8	·00520	·000280	·005480	,,	737	0·84

A TRIALS—*continued.*

Table 10.

Test No.	Jacket Temperatures.		Heat given to Jackets.	
	Inlet.	Outlet.	Per Explosion.	Per cent.
	C.°	C.°	Calories.	
1	15	63	1·43	42
2	15	64	1·29	42
3	15	62	1·10	39
4	9	66	·78	29
5	9	60	·74	30
6	16	58	·83	32
7	11	64	·64	29
8	16	64	·74	30

Table 11.

Test No.	Temperature at end of Adiabatic Expansion.	Heat lost by residue at Exhaust, per explosion.
	C.°	Calorie.
1	1497	0·10
2	1327	0·09
3	1187	0·09
4	1127	0·09
5	1052	0·11
6	1027	0·10
7	952	0·09
8	897	0·11

A TRIALS—*continued.*

Table 12.

Test No.	Work per explosion.	Heat to Jacket, per explosion.	Heat to Exhaust, per explosion.	Radiation, per explosion.	Total.	Heat Expended, per explosion.	Balance.
	Calorie.	Calories.	Calories.	Calorie.	Calories.	Calories.	Per cent.
1	0·57	1·43	1·35	0·06	3·51	3·43	+2·3
2	0·53	1·29	1·18	,,	3·15	3·05	+3·3
3	0·50	1·10	1·13	,,	2·88	2·80	+2·9
4	0·49	0·78	1·19	,,	2·61	2·65	−1·5
5	0·47	0·74	1·13	,,	2·51	2·49	+0·8
6	0·48	0·83	1·02	,,	2·49	2·62	−5·0
7	0·42	0·64	1·08	,,	2·29	2·19	+4·6
8	0·44	0·74	0·84	,,	2·19	2·47	−11·3

Table 13.

Test No.	Weights.			Total Weight, per explosion.	Suction Temp.	Exhaust Temp.	Energy of charge at Exhaust, per explosion.
	Air per explosion.	Gas per explosion.	Clearance residue.				
	Kg.	Kg.	Kg.	Kg.	C.°	C.°	Calories.
1	·00461	·000389	·00143	·006429	153	1097	1·56
2	·00482	·000346	·00154	·006706	140	982	1·38
3	·00494	·000318	·00166	·006918	130	937	1·33
4	·00521	·000307	·00159	·007107	121	947	1·39
5	·00515	·000289	·00188	·007319	111	932	1·40
6	·00525	·000299	·00195	·007499	102	847	1·26
7	·00554	·000255	·00182	·007615	99	857	1·30
8	·00520	·000280	·00241	·007890	85	737	1·12

APPENDIX III.

B TRIALS. (Plate 177.)

Table 1.

Clearance vol. in litres.	Stroke vol. in litres.	Ratio : $\frac{\text{clear vol.}}{\text{cylr. vol.}}$	Clearance surface in cm².		Compression. Absolute.	
			Total.	Jacketed.	Kg. per cm².	Lbs. per sq. inch.
2·509	5·522	0·45	1490	1035	5·02	71

Table 2.

Test No.	Revolutions per minute.	Explosions per minute.	Per cent. of Full Power.
1	196·3	93·9	96
2	197·5	90·7	92
3	199·8	95·0	95
4	196·2	87·1	89
5	205·9	92·8	90
6	197·0	90·8	92
7	206·5	94·1	91
8	202·3	95·5	94
9	203·5	97·3	96

Table 3.

Test No.	Suction Pressure.	Suction Temperature.	Compression.		n in PV^n=Const.
			Pressure.	Temperature.	
	Kg. per cm².	C.°	Kg. per cm².	C.°	
1	1·00	156	4·96	392	1·376
2	,,	143	4·99	376	1·382
3	,,	138	4·92	360	1·369
4	,,	135	4·86	347	1·359
5	,,	123	4·90	334	1·366
6	,,	119	4·86	323	1·359
7	,,	108	5·05	329	1·392
8	,,	99	5·29	342	1·431
9	,,	90	5·36	336	1·443

B TRIALS—(*continued*).

Table 4.

Test No.	Maximum Pressure.	Maximum Temperature.	Volume at Maximum Temperature.	Exhaust.		Mean Pressure, Gross.	n in $PV^n = \text{Const.}$
				Pressure.	Temperature.		
	Kg. per cm^2.	C.°	Litres.	Kg. per cm^2.	C.°	Kg. per cm^2.	
1	15·79	1948	2·64	3·04	1027	4·90	1·483
2	14·00	1745	2·85	3·08	1007	4·66	1·461
3	12·45	1567	2·89	2·91	922	4·22	1·425
4	11·87	1668	3·22	2·98	942	4·44	1·516
5	11·00	1508	3·28	3·18	987	4·34	1·385
6	12·14	1465	2·93	2·81	829	4·06	1·454
7	10·65	1354	3·21	3·01	877	3·97	1·377
8	9·92	1212	3·24	2·94	817	3·61	1·341
9	9·05	1098	3·35	2·81	747	3·34	1·338

Table 5.

Test No.	Explosions per minute.	Mean Pressure, Gross.		Correction for Suction.	Mean Pressure, Net.	I.H.P.		B.P.		Mechanical Efficiency.
						H.P.	Kw.	B.H.P.	Kw.	
		Lbs. per sq. in.	Kg. per cm^2.	Kg. per cm^2.	Kg. per cm^2.					
1	93·9	69·7	4·90	0·11	4·79	5·44	4·06	3·93	2·93	0·72
2	90·7	66·3	4·66	0·11	4·55	4·99	3·72	3·96	2·95	0·79
3	95·0	60·0	4·22	0·11	4·11	4·72	3·52	4·07	3·04	0·86
4	87·1	63·1	4·44	0·13	4·31	4·54	3·39	3·41	2·54	0·75
5	92·8	61·7	4·34	0·12	4·22	4·75	3·54	3·45	2·57	0·73
6	90·8	57·7	4·06	0·12	3·94	4·33	3·23	2·90	2·16	0·67
7	94·1	56·4	3·97	0·12	3·85	4·38	3·27	3·20	2·39	0·73
8	95·5	51·3	3·61	0·11	3·50	4·05	3·02	2·83	2·11	0·70
9	97·3	47·5	3·34	0·11	3·23	3·81	2·84	2·51	1·87	0·66

B TRIALS—*continued.*

Table 6.

Test No.	Gas per Explosion.	Air per Explosion.	Ratio Air to Gas.	Heating Value of Gas, Calories per litre.	Calorie per litre of Mixture.
	Litre.	Litres.			
1	0·680	3·65	5·4	4·813	0·752
2	0·650	3·84	5·9	,,	0·698
3	0·569	3·89	6·8	,,	0·617
4	0·577	4·07	7·0	,,	0·601
5	0·550	4·22	7·7	4·864	0·559
6	0·512	4·17	8·1	4·813	0·529
7	0·490	4·32	8·7	4·864	0·501
8	0·450	4·42	9·8	,,	0·450
9	0·410	4·29	10·5	,,	0·423

Table 7.

Test No.	CO_2 per cent.	O per cent.	Ratio: $\frac{\text{air}}{\text{gas}}$ from CO_2.	Ratio: $\frac{\text{air}}{\text{gas}}$ from O.	Mean.	K_v.	$K_p - K_v$.
1	10·55	1·05	5·47	5·64	5·6	·1865 + ·000117 T	·0721
2	8·60	5·07	6·59	6·93	6·7	·1834 + ·000112 T	·0715
3	8·00	6·25	7·04	7·45	7·2	·1822 + ·000110 T	·0712
4	7·80	6·65	7·21	7·64	7·4	·1817 + ·000109 T	·0711
5	7·40	8·11	8·39	8·37	8·4	·1798 + ·000106 T	·0709
6	6·44	9·19	8·62	9·19	8·9	·1790 + ·000105 T	·0708
7	6·28	9·98	9·80	9·72	9·8	·1777 + ·000103 T	·0706
8	5·78	10·85	10·61	10·53	10·6	·1767 + ·000102 T	·0705
9	5·36	11·73	11·41	11·49	11·4	·1760 + ·000100 T	·0703

B TRIALS—*continued.*

Table 8.

Test No.	Gas per Hour.		Cub. ft. per I.H.P. per hour.	Cub. mètres per kilowatt-hour.	Cub. ft. per B.H.P. hour.	Cub. mètres per Brake kilowatt-hour.	Thermal Efficiency per I.H.P.
	Cub. ft.	M³.					
1	135	3·82	24·8	·94	34·4	1·31	19
2	125	3·54	25·1	·95	31·7	1·20	18·7
3	115	3·26	24·3	·92	28·2	1·07	19·4
4	107	3·03	23·5	·89	31·3	1·19	20·0
5	108	3·06	22·7	·86	31·3	1·19	20·5
6	99	2·80	22·8	·87	34·0	1·29	20·7
7	99	2·80	22·6	·86	30·9	1·17	20·5
8	91	2·58	22·4	·85	32·0	1·21	20·7
9	84	2·38	22·0	·83	33·5	1·27	21·2

Table 9.

Test No.	Weight of Air, per explosion.	Weight of Gas, per explosion.	Air+Gas, per explosion.	Air Temp.	Exhaust Temp.	Calories rejected to Exhaust, per explosion.
	Kg.	Kg.		C.°	C.°	Calories.
1	·00447	·000386	·00486	15	1027	1·21
2	·00471	·000369	·00508	,,	1007	1·21
3	·00477	·000323	·00509	,,	922	1·08
4	·00499	·000327	·00532	,,	942	1·14
5	·00517	·000312	·00548	,,	987	1·24
6.	·00511	·000291	·00540	,,	829	0·98
7	·00530	·000278	·00558	,,	877	1·07
8	·00542	·000255	·00567	,,	817	1·00
9	·00526	·000233	·00549	,,	747	·86

B TRIALS—*continued.*

Table 10.

Test No.	Jacket Temperature.		Heat given to Jackets.	
	Inlet.	Outlet.	Per Explosion.	Per Cent.
	C.°	C.°	Calories.	
1	15	63	1·43	44
2	14	66	1·30	41
3	17	67	1·08	39
4	15	61	1·07	38
5	13	62	0·88	33
6	15	61	0·92	37
7	13·5	65	0·77	32
8	13	62	0·76	35
9	14	61	0·59	29

Table 11.

Test No.	Temperature at end of Adiabatic Expansion.	Heat lost by residue at Exhaust, per explosion.
	C.°	Calorie.
1	1567	0·06
2	1402	0·06
3	1237	0·06
4	1372	0·055
5	1217	0·06
6	1137	0·06
7	1062	0·07
8	932	0·07
9	852	0·08

B TRIALS—*continued.*

TABLE 12.

Test No.	Work per explosion.	Heat to Jacket, per explosion.	Heat to Exhaust, per explosion.	Radiation, per explosion.	Total.	Heat Expended, per explosion.	Balance.
	Calorie.	Calories.	Caloires.	Calorie.	Calories.	Calories.	Per cent.
1	0·62	1·43	1·21	0·06	3·38	3·28	+3·0
2	0·59	1·30	1·21	,,	3·22	3·15	+2·2
3	0·53	1·08	1·08	,,	2·81	2·75	+2·2
4	0·56	1·07	1·14	,,	2·88	2·77	+4·0
5	0·55	0·88	1·24	,,	2·79	2·67	+4·5
6	0·51	0·92	1·05	,,	2·53	2·47	+1·6
7	0·50	0·71	1·07	,,	2·41	2·42	−0·4
8	0·45	0·76	1·00	,,	2·34	2·17	+7·8
9	0·42	0·59	0·86	,,	2·01	1·99	+1·0

TABLE 13.

Test No.	Weights.			Total Weight.	Suction Temp.	Exhaust Temp.	Energy of charge at Exhaust, per explosion.
	Air per explosion.	Gas per explosion.	Clearance residue per explosion.				
	Kg.	Kg.	Kg.	Kg.	C.°	C.°	Calories.
1	·00447	·000386	·00103	·00589	156	1027	1·31
2	·00471	·000369	·00104	·00612	143	1007	1·31
3	·00477	·000323	·00116	·00625	138	922	1·18
4	·00499	·000327	·00099	·00630	135	942	1·22
5	·00517	·000312	·00104	·00652	123	987	1·34
6	·00511	·000291	·00122	·00662	119	877	1·16
7	·00530	·000278	·00127	·00685	108	877	1·20
8	·00542	·000255	·00137	·00704	99	817	1·13
9	·00526	·000233	·00175	·00724	90	747	1·04

APPENDIX IV.

C TRIALS. (Plate 178.)

Table 1.

Clearance vol. in litres.	Stroke vol. in litres.	Ratio: $\frac{\text{clear. vol.}}{\text{cylr. vol.}}$	Clearance surface in cm².		Compression. Absolute.	
			Total.	Jacketed.	Kg. per cm².	Lbs. per sq. inch.
1·852	5·522	0·34	1680	1035	6·51	93

Table 2.

Test No.	Revolutions per minute.	Explosions per minute.	Per cent. of Full Power.
1	198·7	95·2	96
2	197·0	96·4	98
3	200·8	95·1	95
4	199·6	96·3	96
5	198·8	99·1	100
6	194·4	94·1	97
7	201·6	92·5	92
8	202·2	88·9	88

Table 3.

Test No.	Suction Pressure.	Suction Temperature.	Compression.		n in $PV^n = \text{Const.}$
			Pressure.	Temperature.	
	Kg. per cm².	C.°	Kg. per cm².	C.°	
1	1·00	155	6·45	420	1·350
2	,,	151	6·43	412	1·347
3	,,	143	6·73	430	1·380
4	,,	130	6·43	378	1·347
5	,,	120	6·59	377	1·364
6	,,	113	6·09	317	1·307
7	,,	94	6·52	328	1·357
8	,,	78	6·81	327	1·388

C TRIALS—(*continued*).

Table 4.

Test No.	Maximum Pressure.	Maximum Temperature.	Volume at Maximum Temperature.	Exhaust.		Mean Pressure, Gross.	n in $PV^n = $Const.
				Pressure.	Temperature.		
	Kg. per cm².	C.°	Litres.	Kg. per cm².	C.°	Kg. per cm².	
1	14·75	1749	2·36	2·96	992	4·69	1·413
2	14·39	1677	2·36	2·93	967	4·55	1·395
3	17·32	1677	1·99	2·83	907	4·41	1·382
4	12·32	1480	2·60	2·85	877	4·25	1·405
5	11·72	1331	2·57	2·88	857	3·99	1·332
6	11·75	1224	2·44	2·78	797	3·82	1·307
7	9·65	1154	2·98	2·98	817	3·73	1·299
8	9·20	977	2·85	2·93	757	3·33	1·204

Table 5.

Test No.	Explosions per minute.	Mean Pressure, Gross.		Correction for Suction.	Mean Pressure, Net.	I.H.P.		B.P.		Mechanical Efficiency.
						H.P.	Kw.	B.H.P.	Kw.	
		Lbs. per sq. in.	Kg. per cm².	Kg. per cm².	Kg. per cm².					
1	95·2	66·7	4·69	0·12	4·57	5·27	3·93	4·04	3·01	0·77
2	96·4	64·7	4·55	0·11	4·44	5·19	3·87	4·16	3·10	0·80
3	95·1	62·7	4·41	0·12	4·29	4·93	3·68	3·84	2·86	0·78
4	96·3	60·4	4·25	0·12	4·13	4·81	3·59	3·48	2·60	0·72
5	99·1	56·7	3·99	0·11	3·88	4·65	3·47	3·66	2·73	0·79
6	94·1	54·3	3·82	0·12	3·70	4·21	3·14	3·17	2·37	0·75
7	92·5	53·0	3·73	0·13	3·60	4·03	3·01	2·45	1·83	0·61
8	88·9	47·3	3·33	0·14	3·19	3·43	2·56	2·05	1·53	0·60

C TRIALS—*continued.*

Table 6.

Test No.	Gas per Explosion.	Air per Explosion.	Ratio Air to Gas.	Heating Value of Gas, Calories per litre.	Calorie per litre of Mixture.
	Litre.	Litres.			
1	0·687	3·41	5·0	5·0	0·833
2	0·662	3·50	5·2	,,	0·806
3	0·611	3·58	5·8	,,	0·735
4	0·523	3·83	7·3	,,	0·603
5	0·499	3·94	7·9	,,	0·562
6	0·481	4·09	8·5	,,	0·526
7	0·427	4·19	9·8	,,	0·463
8	0·413	4·25	10·3	,,	0·443

Table 7.

Test No.	CO_2 per cent.	O per cent.	Ratio: $\frac{\text{air}}{\text{gas}}$ from CO_2.	Ratio: $\frac{\text{air}}{\text{gas}}$ from O.	Mean.	K_v.	$K_p - K_v$.
1	10·78	0·82	5·84	5·66	5·7	·1862 + ·000116 T	·0720
2	10·30	2·00	6·09	5·98	6·0	·1854 + ·000115 T	·0718
3	9·12	4·12	6·80	6·66	6·7	·1834 + ·000112 T	·0715
4	7·92	7·14	7·74	8·00	7·9	·1807 + ·000108 T	·0710
5	6·94	8·12	8·75	8·57	8·7	·1793 + ·000106 T	·0709
6	6·44	9·20	9·39	9·31	9·3	·1784 + ·000104 T	·0706
7	5·39	10·99	11·11	10·88	11·0	·1764 + ·000101 T	·0704
8	4·72	12·45	12·60	12·66	12·6	·1750 + ·000099 T	·0701

C TRIALS—*continued.*

Table 8.

Test No.	Gas per Hour.		Cub. ft. per I.H.P. per hour.	Cub. mètres per kilowatt-hour.	Cub. ft. per B.H.P. hour.	Cub. mètres per Brake kilowatt-hour.	Thermal Efficiency per I.H.P.
	Cub. ft.	M³.					
1	139	3·94	26·3	1·00	34·3	1·30	17·2
2	135	3·82	26·1	·99	32·5	1·23	17·3
3	123	3·48	25·0	·95	32·1	1·22	18·2
4	107	3·03	22·2	·84	30·7	1·17	20·4
5	105	2·97	22·6	·86	28·6	1·09	20·0
6	96	2·72	22·8	·87	30·3	1·15	19·9
7	84	2·38	20·7	·79	34·1	1·29	21·9
8	78	2·21	22·7	·86	38·0	1·44	19·9

Table 9.

Test No.	Weight of Air, per explosion.	Weight of Gas, per explosion.	Air+Gas, per explosion.	Air Temp.	Exhaust Temp.	Calories rejected to Exhaust, per explosion.
	Kg.	Kg.		C.°	C.°	Calories.
1	·00418	·000390	·00457	15	992	1·09
2	·00429	·000376	·00467	,,	967	0·99
3	·00439	·000347	·00474	,,	907	0·99
4	·00470	·000297	·00500	,,	877	0·99
5	·00483	·000283	·00511	,,	857	0·97
6	·00501	·000273	·00528	,,	797	0·91
7	·00514	·000242	·00538	,,	817	0·94
8	·00521	·000234	·00544	,,	757	0·86

C TRIALS—*continued.*

Table 10.

Test No.	Jacket Temperatures.		Heat given to Jackets.	
	Inlet.	Outlet.	Per Explosion.	Per cent.
	C.°	C.°	Calories.	Per cent.
1	18	64	1·41	41
2	17	65	1·33	40
3	18	66	1·29	42
4	17	64	·97	37
5	18	62	·90	36
6	15	65	·88	37
7	16	61	·64	30
8	16	68	·55	26

Table 11.

Test No.	Temperature at end of Adiabatic Expansion.	Heat lost by residue at Exhaust, per explosion.
	C.°	Calorie.
1	1372	0·050
2	1302	0·045
3	1247	0·050
4	1142	0·045
5	1002	0·050
6	897	0·040
7	897	0·060
8	712	0·070

C TRIALS—*continued.*

Table 12.

Test No.	Work per explosion.	Heat to Jacket, per explosion.	Heat to Exhaust, per explosion.	Radiation, per explosion.	Total.	Heat Expended, per explosion.	Balance.
	Calorie.	Calories.	Calories.	Calorie.	Calories.	Calories.	Per cent.
1	0·59	1·41	1·09	0·06	3·20	3·43	−6·7
2	0·57	1·33	0·99	,,	2·99	3·30	−9·1
3	0·55	1·29	0·99	,,	2·94	3·05	−3·6
4	0·54	0·97	0·99	,,	2·60	2·62	−0·6
5	0·50	0·99	0·97	,,	2·48	2·49	−0·4
6	0·48	0·88	0·91	,,	2·37	2·39	−0·8
7	0·47	0·64	0·94	,,	2·17	2·14	+1·4
8	0·42	0·55	0·86	,,	1·95	2·07	−5·3

Table 13.

Test No.	Weights.			Total Weight, per explosion.	Suction Temp.	Exhaust Temp.	Energy of charge at Exhaust, per explosion.
	Air per explosion.	Gas per explosion.	Clearance residue, per explosion.				
	Kg.	Kg.	Kg.	Kg.	C.°	C.°	Calories.
1	·00418	·000390	·00082	·00539	155	992	1·14
2	·00429	·000376	·00080	·00547	151	967	1·12
3	·00439	·000347	·00088	·00562	143	907	1·04
4	·00470	·000297	·00088	·00588	130	877	1·03
5	·00483	·000283	·00093	·00604	120	857	1·93
6	·00501	·000273	·00089	·00617	113	797	·95
7	·00514	·000242	·00117	·00655	94	817	1·06
8	·00521	·000234	·00143	·00687	78	757	1·01

APPENDIX V.

D TRIALS. (Plate 179.)

Table 1.

Clearance vol. in litres.	Stroke vol. in litres.	Ratio: $\frac{\text{clear. vol.}}{\text{cylr. vol.}}$	Clearance surface in cm².		Compression. Absolute.	
			Total.	Jacketed.	Kg. per cm².	Lbs. per sq. inch.
1·389	5·522	0·25	1550	905	8·72	124

Table 2.

Test No.	Revolutions per minute.	Explosions per minute.	Per cent. of Full Power.
1	199·0	92·7	93
2	196·7	92·3	94
3	199·1	98·0	98
4	200·3	96·6	96
5	202·0	95·1	94
6	202·5	95·0	94
7	200·7	92·7	92
8	200·2	93·7	94
9	200·5	92·9	93
10	202·0	95·4	94

Table 3.

Test No.	Suction Pressure.	Suction Temperature.	Compression.		n in $PV^n = \text{Const.}$
			Pressure.	Temperature.	
	Kg. per cm².	C.°	Kg. per cm².	C.°	
1	1·00	143	8·66	452	1·345
2	,,	140	8·92	468	1·364
3	,,	132	8·82	445	1·357
4	,,	128	8·70	429	1·349
5	,,	115	8·70	406	1·349
6	,,	110	8·85	409	1·359
7	,,	98	8·66	373	1·345
8	0·95	84	8·36	359	1·345
9	1·00	84	8·82	360	1·357
10	,,	69	8·72	327	1·350

D TRIALS—(*continued*).

Table 4.

Test No.	Maximum Pressure.	Maximum Temperature.	Volume at Maximum Temperature.	Exhaust.		Mean Pressure, Gross.	n in PV^n = Const.
				Pressure.	Temperature.		
	Kg. per cm².	C°.	Litres.	Kg. per cm².	C.°	Kg. per cm².	
1	13·60	1437	2·09	2·73	862	4·10	1·344
2	18·28	1509	1·63	2·65	822	4·21	1·338
3	14·80	1442	1·98	2·83	872	4·35	1·324
4	14·41	1454	2·07	2·90	887	4·47	1·327
5	14·05	1372	2·09	2·88	842	4·36	1·327
6	13·81	1245	1·99	2·75	777	3·99	1·294
7	12·18	1145	2·17	2·86	787	3·88	1·251
8	11·85	1094	2·12	2·72	749	3·70	1·245
9	12·60	1023	1·99	2·73	702	3·63	1·230
10	12·00	897	1·97	2·66	637	3·34	1·199

Table 5.

Test No.	Explosions per minute.	Mean Pressure, Gross.		Correction for Suction.	Mean Pressure, Net.	I.H.P.		B.H.P.		Mechanical Efficiency.
						H.P.	Kw.	H.P.	Kw.	
		Lbs. per sq. in.	Kg. per cm².	Kg. per cm².	Kg. per cm².					
1	92·7	58·3	4·10	0·12	3·98	4·46	3·33	3·71	2·77	0·83
2	92·3	59·9	4·21	0·12	4·09	4·57	3·41	3·41	2·54	0·75
3	98·0	61·9	4·35	0·11	4·24	4·96	3·70	3·80	2·84	0·77
4	96·6	63·6	4·47	0·12	4·35	5·08	3·79	3·71	2·77	0·73
5	95·1	62·0	4·36	0·12	4·24	4·88	3·64	3·51	2·62	0·72
6	95·0	56·7	3·99	0·12	3·87	4·45	3·32	3·10	2·31	0·70
7	92·7	55·2	3·88	0·13	3·75	4·21	3·14	2·91	2·17	0·69
8	93·7	52·6	3·70	0·12	3·58	4·06	3·03	2·81	2·10	0·69
9	92·9	51·6	3·63	0·12	3·51	3·94	2·94	2·70	2·01	0·69
10	95·4	47·5	3·34	0·12	3·22	3·71	2·77	2·37	1·77	0·64

D TRIALS—(*continued*).

Table 6.

Test No.	Gas per Explosion.	Air per Explosion.	Ratio Air to Gas.	Heating Value of Gas, Calories per litre.	Calorie per litre of Mixture.
	Litre.	Litres.			
1	0·580	3·71	6·5	4·864	0·648
2	0·570	3·84	6·8	,,	0·624
3	0·520	3·87	7·4	,,	0·579
4	0·510	4·06	8·0	4·978	0·553
5	0·485	4·06	8·4	,,	0·529
6	0·450	4·22	9·4	,,	0·479
7	0·430	4·28	9·9	,,	0·457
8	0·403	4·31	10·7	,,	0·425
9	0·400	4·36	10·9	,,	0·418
10	0·371	4·32	11·7	,,	0·392

Table 7.

Test No.	CO_2 per cent.	O per cent.	Ratio: $\frac{\text{air}}{\text{gas}}$ from CO_2.	Ratio: $\frac{\text{air}}{\text{gas}}$ from O.	Mean.	K_v.	$K_p - K_v$.
1	9·32	4·71	6·75	6·70	6·7	·1834+·000112 T	·0715
2	9·02	5·32	6·96	6·95	7·0	·1827+·000111 T	·0713
3	8·10	6·92	7·70	7·69	7·7	·1811+·000108 T	·0711
4	7·90	7·42	7·96	8·20	8·1	·1804+·000107 T	·0710
5	6·93	9·69	9·61	9·30	9·2	·1785+·000105 T	·0707
6	6·61	9·95	9·42	9·99	9·7	·1778+·000103 T	·0706
7	5·76	10·94	10·75	10·94	10·8	·1765+·000101 T	·0705
8	5·28	11·93	11·68	12·10	11·9	·1756+·000100 T	·0702
9	5·19	11·80	11·88	11·93	11·9	·1756+·000100 T	·0702
10	4·59	12·90	13·37	13·51	13·4	·1745+·000099 T	·0700

D TRIALS—(*continued*).

Table 8.

Test No.	Gas per Hour.		Cub. ft. per I.H.P. hour.	Cub. mètres per kilowatt-hour.	Cub. ft. per B.H.P. hour.	Cub. mètres per brake kilowatt-hour.	Thermal Efficiency per I.H.P.
	Cub. ft.	M^3.					
1	115	3·26	25·7	·98	30·9	1·17	18·1
2	112	3·17	24·4	·93	32·7	1·24	19·1
3	109	3·09	21·9	·83	28·6	1·09	21·2
4	104	2·94	20·5	·78	28·1	1·07	22·1
5	98	2·77	20·0	·76	27·9	1·06	22·7
6	91	2·58	20·4	·77	29·2	1·11	22·3
7	85	2·41	20·1	·76	29·1	1·10	22·7
8	80	2·27	19·7	·75	28·5	1·08	23·1
9	79	2·24	20·0	·76	29·2	1·11	22·7
10	75	2·12	20·2	·77	31·6	1·20	22·5

Table 9.

Test No.	Weight of Air, per explosion.	Weight of Gas, per explosion.	Air+Gas, per explosion.	Air Temp.	Exhaust. Temp.	Calories rejected to Exhaust, per explosion.
	Kg.	Kg.		C.°	C.°	Calories.
1	·00455	·000329	·00488	15	862	0·96
2	·00471	·000324	·00503	,,	822	0·93
3	·00474	·000295	·00504	,,	872	0·99
4	·00498	·000289	·00527	,,	887	1·05
5	·00498	·000275	·00525	,,	842	0·98
6	·00517	·000255	·00542	,,	777	0·91
7	·00525	·000244	·00549	,,	787	0·92
8	·00528	·000229	·00551	,,	749	0·86
9	·00535	·000227	·00558	,,	702	0·81
10	·00530	·000211	·00551	,,	637	0·71

D TRIALS—*continued.*

Table 10.

Test No.	Jacket Temperature.		Heat given to Jackets.	
	Inlet.	Outlet.	Per Explosion.	Per Cent.
	C.°	C.°	Calories.	
1	12	65	1·09	38
2	12	62	1·18	43
3	14	62	0·84	33
4	15	64	0·91	36
5	14	66	0·77	32
6	14	60	0·80	36
7	15	61	0·66	31
8	15	66	0·60	30
9	15	63	0·61	31
10	15	64	0·52	28

Table 11.

Test No.	Temperature at end of Adiabatic Expansion.	Heat lost by residue at Exhaust per explosion.
	C.°	Calorie.
1	1062	0·02
2	1047	0·01
3	1047	0·02
4	1072	0·01
5	1002	0·03
6	877	0·02
7	797	0·03
8	707	0·03
9	687	0·03
10	592	0·04

D TRIALS—*continued.*

Table 12.

Test No.	Work per explosion.	Heat to Jacket, per explosion.	Heat to Exhaust, per explosion.	Radiation, per explosion.	Total.	Heat Expended, per explosion.	Balance.
	Calorie.	Calories.	Calories.	Calorie.	Calories.	Calories.	Per cent.
1	0·51	1·09	0·96	0·06	2·64	2·85	−7·4
2	0·53	1·18	0·93	,,	2·71	2·77	−2·2
3	0·54	0·84	0·99	,,	2·45	2·54	−3·5
4	0·56	0·91	1·05	,,	2·59	2·54	+2·0
5	0·55	0·77	0·98	,,	2·39	2·42	−1·2
6	0·50	0·80	0·91	,,	2·29	2·24	+2·2
7	0·49	0·66	0·92	,,	2·16	2·14	+0·9
8	0·46	0·60	0·86	,,	2·01	2·02	−0·5
9	0·45	0·61	0·81	,,	1·96	1·99	−1·5
10	0·42	0·52	0·71	,,	1·75	1·84	−4·9

Table 13.

Test No.	Weights.			Total Weight.	Suction Temp.	Exhaust Temp.	Energy of charge at Exhaust, per explosion.
	Air per explosion.	Gas per explosion.	Clearance residue per explosion.				
	Kg.	Kg.	Kg.	Kg.	C.°	C.°	Calories.
1	·00455	·000329	·000400	·00528	143	862	0·91
2	·00471	·000324	·000304	·00534	140	822	0·86
3	·00474	·000295	·000435	·00547	132	872	0·95
4	·00498	·000289	·000276	·00554	128	887	0·99
5	·00498	·000275	·000505	·00576	115	842	1·02
6	·00517	·000255	·000433	·00586	110	777	0·87
7	·00525	·000244	·000578	·00607	98	787	0·93
8	·00528	·000229	·000824	·00633	84	749	0·91
9	·00535	·000227	·000763	·00634	84	702	0·84
10	·00530	·000211	·001130	·00664	69	637	0·79

APPENDIX VI.

HEAT ADDITIONS. CALORIES PER EXPLOSION.

Trial No.	Ratio: $\frac{\text{Air}}{\text{Gas}}$	Heat added at Constant Volume.	Heat added at Constant Pressure.	Change of Internal Energy during Expansion.	Gross work done during Expansion.	Gross work done during Compression.	Change of Internal Energy during Compression.
A_6	10·3	1·329	0·807	0·902	0·568	0·239	0·181
B_7	9·8	1·120	0·929	0·953	0·626	0·278	0·303
C_7	11·0	0·42	1·19	0·616	0·534	0·308	0·303
D_7	10·8	0·36	1·04	0·594	0 626	0·351	0·334

HEAT GIVEN TO JACKET.

Trial No.	During Constant Volume and Constant Pressure.	During Expansion.	During Compression.	Total.	Measured.
A_6	0·48	0·33	0·06	0·87	0·83
B_7	0·37	0·33	0·02	0·68	0·77
C_7	0·53	0·08	0·01	0·62	0·64
D_7	0·74	—0·03	0·02	0·73	0·66

APPENDIX VII.

Table showing Effect of Change of Compression. Lighting Gas.

Trial No.	Ratio of Clearance Volume to Cylinder Volume.	Jacketed Surface per cent. of Clearance Surface.	Compression in Atmospheres.	Revolutions per Minute.	Explosions per Minute.	Temperatures C°.					Power.		Mechanical Efficiency.
						Suction.	Compression.	Explosion Maximum.	End of Adiabatic Expansion.	Exhaust.	I.H.P.	B.H.P.	
A 7	0·57	71	3·75	206·8	99·2	99	311	1145	952	857	3·86	2·72	0·70
B 9	0·45	69	4·86	203·5	97·3	90	336	1098	852	747	3·81	2·51	0·66
C 7	0·34	62	6·30	201·6	92·5	94	328	1154	897	817	4·03	2·45	0·61
D 8	0·25	58	8·44	200·2	93·7	84	359	1094	707	749	4·06	2·81	0·69

Trial No.	Exhaust.		Ratio Air to Gas.	Gas. Cubic feet per hour.		Lower Heating Value of Gas. B.T.U. per cubic foot.	Temperature of Jacket Water.		Heat Balance Percentages.					Thermal Efficiency on B.H.P. per cent.
	CO_2 per cent.	O per cent.		Per I.H.P.	Per B.H.P.		Inlet. C°.	Outlet. C°.	I.H.P.	Jacket.	Exhaust.	Radiation.	Total.	
A 7	5·83	11·11	10·6	24·6	34·9	547	11	64	18·9	29·0	49·4	2·7	100·0	13·2
B 9	5·36	11·73	11·4	22·0	33·5	547	14	61	21·2	29·0	43·2	3·0	96·4	14·0
C 7	5·39	10·99	11·0	20·7	34·1	562	16	61	21·9	30·0	43·9	2·8	98·6	13·4
D 8	5·28	11·93	11·9	19·7	28·5	559	15	66	23·1	30·0	42·6	3·0	98·7	15·9

APPENDIX VIII.

Temperature of Charge during Expansion and Suction.

Wire 0·0025 inch diameter.

(Plate 180.)

Test No.		X_1	X_2	X_3	X_4
Ratio Air to Gas.		11·3	11·6	12·1	12·1
Point of Stroke.		Temperatures. C.°			
0·05		1460	1030	1216	1340
0·12		1440	1280	1294	1290
0·22		1440	1220	1278	1250
0·33		1260	1170	1192	1200
0·41		1245	1085	1187	1170
0·52		1245	1030	1100	1130
0·63		1070	880	1000	1000
0·74		1030	880	945	945
0·87		945	750	890	850
Suction.		40	32	35	48
Constants of Thermometers.					
Ice Point.	Before.	0·275	0·714	0·272	0·690
	After.	0·251	0·690	0·274	wire broke.
Fundamental Interval.	Before.	0·103	0·262	0·103	0·265
	After.	0·99	0·265	0·105	—

Wire 0·0020 inch diameter.
(Plate 180.)

Test No.		Y_1	Y_2	Y_3
Ratio Air to Gas.		11·8	13·5	13·7
Point of Stroke.		Temperatures. C.°		
0·1		1340	1190	1100
0·2		1290	1140	1100
0·3		1170	1070	1040
0·4		1070	1000	985
0·5		905	945	905
0·6		840	840	760
0·7		815	775	700
0·8		815	740	660
0·9		750	675	630
Suction.		30	55	31
Constants of Thermometers.				
Ice Point.	Before.	0·426	0·380	0·478
	After.	0·422	0·380	0·476
Fundamental Interval.	Before.	0·162	0·142	0·186
	After.	0·162	0·142	0·186

WIRE 0·0015 INCH DIAMETER.

(Plate 181.)

Test No.	Z_1	Z_6	Test No.	Z_2	Z_3	Z_4	Z_5	Z_7	Z_8	Z_9	Z_{10}
Ratio.	11·0	12·4	Ratio.	12·2	12·2	12·2	12·2	12·6	12·8	12·8	12·9
Point of Stroke.	Temperatures.		Point of Stroke.	Temperatures C.°							
0·05	1490	1290	0·1	1230	1325	1570	1520	1560	1310	1300	1400
0·12	1470	1250	0·2	1160	1200	1470	1420	1440	1245	1250	1230
0·22	1290	1100	0·3	1100	1120	1370	1370	1325	1170	1190	1210
0·33	1170	1040	0·4	1040	1010	1260	1240	1222	1100	1130	1060
0·41	1085	1040	0·5	910	860	1160	1130	1130	1010	1020	910
0·52	945	945	0·6	870	940	1120	1100	1070	910	950	870
0·63	880	880	0·7	810	820	1020	1030	1000	830	860	770
0·74	740	840	0·8	710	740	980	940	920	730	850	730
0·87	700	760	0·9	650	720	890	900	850	690	750	730
Suction.	61	49	Suction.	37	41	41	28	56	42	34	54

CONSTANTS OF THERMOMETERS.

Ice Pt. Before.	1·067	·197	Ice Pt. Before.	·734	·734	·641	·449	·778	·551	·464	·505
,, After.	wire broke	wire broke	,, After.	·734	wire broke	·614	·421	wire broke	·551	·449	·524
F. I. Before.	·404	·090	F. I. Before.	·273	·271	·225	·176	·299	·216	·180	·197
,, After.	—	—	,, After.	·271	—	·239	·179	—	·215	·176	·209

Z_4, Z_5, Z_9 have long Compensators.

APPENDIX IX.

Experiments on Firing the Charge at different percentages of Stroke.

Test No.	Compression lbs. per sq. in.	Nom. Ratio Air to Gas.	Firing Point percentage of Stroke.
B_7	71	8·7	0·76
B_8	,,	9·8	0·68
D_3	124	7·4	0·97
D_4	,,	8·0	0·96
D_5	,,	8·4	0·88
D_7	,,	9·9	0·87
D_8	,,	10·7	0·86
D_{10}	,,	11·7	0·74

Experiment on Temperature during Compression.

Point 0 = beginning of compression.

Point of Stroke.	Temp. C.° Absolute.	Pressure. Kg. per cm².	Volume. Litres.	$\frac{PV}{T}$
0	299	1·077	7·567	0·0272
0·1	307	1·179	7·015	0·0269
0·2	315	1·311	6·463	0·0269
0·3	316	1·472	5·910	0·0275
0·4	324	1·676	5·358	0·0277
0·5	334	1·940	4·806	0·0279
0·6	344	2·277	4·254	0·0281
0·7	355	2·715	3·702	0·0282
0·8	377	3·314	3·149	0·0277
0·9	402	4·193	2·597	0·0271

Experiment comparing Temperatures measured with indicator open and shut.

	Indicator shut.	Indicator open.
	C.°	C.°
0·2 of stroke.	1150	1190
0·8 „ „	939	988

Radiation Test.

Inlet.	Outlet.	Heat radiated per hour.	Mean Temp.	Air Temp.
C.°	C.°	Calories.	C.°	C.°
74·2	62·5	436	68·3	16
69·3	58·8	376	64·0	16·2
59·5	51·2	360	55·3	17·0

Trial for CO *with cooled Exhaust.*

Revolutions per minute.	CO_2.	O.	CO.
180	8·03	6·31	0

Discussion.

The President was sure the Members would agree with him that the Report, which they had just heard, embodied the results of an enormous amount of hard conscientious work. Professor Burstall had not only conducted a very large number of most careful experiments, but he had devised the means by which those experiments were carried out, and the perfecting of those appliances had made very heavy demands on his time. The Report appeared to him to open up two lines of discussion which were more or less separate; namely, first a criticism of the experimental methods which Professor Burstall had devised, and secondly, a discussion of the results which he had obtained by those methods. The first of these lines of discussion was of great importance, because the experiments now described were the early ones of what he hoped would be a prolonged series, and it was thus very desirable to consider carefully every point in the progress of the work. He hoped, therefore, that the speakers would give full attention to both divisions of the Report. Before calling upon the Members to discuss the communication however, he asked them to pass by acclamation a cordial vote of thanks to Professor Burstall for the great pains he had devoted to the work, and the trouble he had taken in bringing the results forward in such a very able way.

The vote was carried by acclamation.

Professor Burstall, before the discussion began, wished to allude to certain points that struck him as important from the practical point of view. A large amount of the Report necessarily was devoted to theoretical considerations. He first drew attention to the question of ignition. It was, he believed, pretty generally accepted that for quite small engines, such as was used in the research, the hot tube was the most useful for ordinary practical running. When, however, a large engine was taken into consideration, the results of the researches showed that electric ignition possessed certain very great advantages. With a hot tube the ignition might

(Professor Burstall.)

at times be slightly delayed, but with the electric ignition, provided there was a sufficient volume of spark produced, it was hardly possible to fail to fire the charge; and even slight delay in firing the charge in an engine of say 300 or 400 H.P. was a serious matter. He trusted that the English makers would very soon follow the Continental practice, and put in electric ignition with all engines beyond 50 H.P., as a matter of course. With regard to the influence of compression, a special Table was given (page 1083) which showed that influence keeping the ratio of air to gas approximately constant. The change in the thermal efficiency was not as much as it would have been, had it been possible to construct an engine with the same ratio of cold surface in all cases. In series A and B the change of compression was produced by inserting packing pieces on the big end of the connecting-rod; in C and D a junk ring bolted to the main body of the piston had to be employed, and the influence of that was certainly to check the increased economy which had been given by the compression. The results which were shown diagrammatically at the top of Plate 182 were of interest, and especially so for the following reasons. It applied to the whole thirty-eight tests. That was, as far as he knew, the first time a suction temperature had been ever determined at all, and it would be noticed that the temperature varied from some 140° C. down to as low as 64° C. Those temperatures were very much higher than previous authorities had considered to be the case, and the high value of the suction temperature explained at once one of the reasons for the increased economy of the modern scavenger engine. If the temperature of the suction charge could be reduced by some 30°, the quantity of air and gas sucked into the cylinder would be increased nearly 10 per cent., and, as the losses to the wall were not proportional to the weight of the charge but to its temperature, the result was an increase in the average mean pressure on the piston. Of course that was produced partially by water-jacketing pistons and all the clearing space, and it was also produced by an efficient scavenger, which cleared out the whole of the residue and cooled the cylinder walls. In the heat balances he had altered somewhat what had been hitherto customary, and had not closed the cycle; that was, the heat additions had been calculated from suction temperature which was say 60° C. to 80° C., and he finished up the exhaust at a temperature of 15° C., leaving of course a vacancy between the two. That was a matter, he was quite well aware, about which a great many people would not agree with him, but he thought it was reasonable to suppose that the cycle was an open one.

With regard to the temperature tests, they were of very great interest indeed, because they served to show certain phenomena that no tests made with an indicator could possibly reveal. First of all, they proved fairly conclusively that combustion was complete at a maximum temperature, and next that during expansion the change behaved as a perfect gas. Both those points had been doubted, and in past years the after-burning formed a prolific cause of dispute amongst the various authorities. He thought it was necessary to look to the existence of after-burning, so called, as merely due to the neglect of the possibilities of a valuable specific heat. The variability of the temperature throughout the cylinder took him with entire surprise. He had hitherto looked upon it as an absolute impossibility to consider that the temperature throughout the cylinder was not uniform, owing to the enormous velocity of flame propagation which took place when the charge was ignited. However, all his experimental results had tended in the same direction, and he should not be quite satisfied until he had determined exactly how the temperature varied in the cylinder, assuming a cylinder in which the variability of temperature could have been found. In the case under consideration it would have been useless, because the cylinder was not a symmetrical one. He trusted at some future date he might be able to say something more on that interesting peculiarity.

Dr. Alex. B. W. Kennedy, Past-President, and Chairman of the Gas-Engine Research Committee, said the duties of the chairman of a Research Committee, so far as the Committee was concerned, were simple and pleasant. He sat by and occasionally aided with such advice as he could give, but he had no work to do, and he would not attempt to take any credit for the work that had been done. He was

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very glad, however, to have been connected with the work, even in that somewhat idle capacity. The President had indicated pretty clearly the two lines into which the work of the Research Committee as a whole, and of perhaps any Research Committee, had divided itself. In the present case no doubt there had had to be an endeavour to find out the exact conditions under which work was done in a gas-engine, and when that had been found out there had been, or would be, an attempt to apply those investigations to making improvements in the gas-engine. Practically it might be said, however, that the first of these considerations only appeared in Professor Burstall's work so far as it had gone; that was, his endeavour had been almost entirely confined to investigating the exact working conditions of the fluid in the gas-engine. He knew Professor Burstall would not say, and in fact he had not said, that the investigations were at all complete, but he thought it might be fairly said that the work of the Committee, as done by Professor Burstall, had gone further, more deeply, and more thoroughly into the investigation of those conditions than any previous work.

With regard to the second point, applying the results to practical work, that was to come. One of the first things in connection with it was naturally the carrying out of experimental work on an engine, which much more nearly resembled the size of engine actually used in practice. He thought the President was going to say something about that, but as he had not done so, he would have the pleasure of first mentioning to the members that at the Council Meeting that day certain arrangements had been made by means of which a large gas-engine of 150 H.P., which was going to be put down at the Birmingham University, could be used, under Professor Burstall, for further experiments in continuation of the work of the Research Committee. That, he was sure, would give results which would have a more direct bearing on practical gas-engine design than the result with a 5-H.P. gas-engine. At the same time, he thought that the criticism which he remembered to have been applied to the work of the Committee before, that the engine was so small that the experiments were practically useless altogether, was a criticism that might be properly called "cheap." It was perfectly obvious that if it had been practicable to make tests on a much larger engine, they would have been made. But he was not aware that even the gentlemen whose interests were most intimately connected with the progress of the work had ever come forward with enthusiasm to help the Committee in getting a 100-H.P. engine, or anything of that kind. Therefore he thought criticism of that sort was really not worth making. The experiments were none the less true, none the less accurate, and none the less helpful to finding out what was going on in the engine, so far as they went, than if they had been done on a much larger machine. He was happy to think, however, that owing to the interest which, through Professor Burstall, the Birmingham University was able to take in the work, results would be obtained which, although not more important from the first of the two points of view which he had mentioned, would, on account of their larger scale, be much more valuable from the second point of view.

With regard to the Report itself he had only one bit of fault-finding. Professor Burstall said (page 1036) that "For the convenience of comparison a few leading figures have been given in the English units also." If Professor Burstall had said that for the convenience of engineering students in some colleges a few figures might be given in the metric system, he believed he would have hit the mark much more nearly. It might be that he, Professor Kennedy, was an old fogey. He could not himself "see" kilogrammes-per-square-centimètre, and as long as he worked in inches and pounds he was going to talk about pounds and square inches. It might be, as he had said, that he was so hopeless an old fogey that everybody was using the other units except himself, but he had his doubts. He strongly suspected that if the members in the room were canvassed, it would be found that about ten to one used pounds and inches and one to ten used kilogrammes and centimètres.

With regard to the things to be aimed at, there were two things Professor Burstall had been trying to get—a complete analytical history of the gas at different times during the stroke, and a complete temperature record of the gas at different portions of the stroke. The analysis, by very ingenious arrangements, he appeared to have

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obtained pretty completely. The temperature of the gas was, as he had told them, only complete to a certain limited extent. The Callendar thermometer, which he agreed was by far the best instrument for measurements of that kind, was a very delicate instrument, and would not stand the tremendous shocks that it got from explosions in an engine working under normal conditions. Therefore in the latter Tables, experiments X, Y, Z, in which the temperatures were measured very completely indeed by the ingenious arrangements described in the Paper, the engine was running dead slow, and was only exploding once out of six times instead of once out of twice, because there was the physical difficulty that if the engine was allowed to run fast the measuring instrument was broken. That difficulty seemed to have been insurmountable hitherto, but whether it would be always insurmountable or not he did not know. He hoped not. In any case it was not apparently a fatal difficulty, because in spite of it many interesting results had been obtained. If he understood the Report rightly—and he spoke to Professor Burstall about one point of it before coming into the room—the latter experiments, the slow experiments, were the only ones in which the temperatures had been actually *measured*. In the other experiments the temperatures had been calculated from a given suction temperature, and the suction temperature itself was obtained by calculation from observations and chemical analysis. He thought that was practically what it amounted to.

Professor Burstall said that it was so.

Dr. Kennedy said he hoped Professor Burstall would explain exactly what he meant by "suction temperature," because it was a little uncertain. He took it that it meant the temperature of the charge after it had completely filled up the cylinder.

Professor Burstall said that was so.

Dr. Kennedy said that, clearly if the suction temperature so defined was found, all the other temperatures could be calculated without very much error. The temperatures given in connection with experiments A, B, C, and D, had been all based on and calculated from the calculated suction temperature which came in Table 3 of each set. At some points in the experiments Professor Burstall arrived at the very interesting result that his calculated temperatures on the X, Y, and Z, experiments did not appear to agree with the actual measured temperatures, and then came in the really extremely interesting question of the non-uniformity of temperature throughout the burning mass, which seemed to be quite clearly indicated as far as Professor Burstall had gone. He hoped that in another engine it might be possible to find a position in which the mean temperatures could be measured, so as to see whether they agreed with the temperatures calculated.

There was an observation (page 1043) which he was very glad to emphasise: "Gas-engines are only utilising about one-third of their total temperature range, when working under best conditions, while in steam-engines more than three-quarters of the temperature range is utilised." That was another way of saying that, in any heat-engine in which the theoretical efficiency was very high, the difficulty of reaching that efficiency was also high. For instance, with an engine which could possibly reach the efficiency of 70 per cent., it would be found much more difficult to realise in practice a quarter of that efficiency than if the theoretical efficiency were only 40 per cent. The same thing applied to steam-engines very strikingly. It was much more easy to get a comparatively good result in what he might call a comparatively low efficiency engine than in a comparatively high one. The thing was still more striking in the case of a gas-engine, whose theoretical efficiency was so very much higher than the steam-engine.

He quite agreed with Professor Burstall as to the method of calculating the heating value of the gas, and thought that this was a very important matter.

As he had used the Callendar thermometer a great deal, he would like to say one word about it. Professor Burstall said that moisture by wetting the asbestos destroyed the insulation. He had used those thermometers for getting steam temperatures, and they were the only

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satisfactory means he had found for getting those temperatures; but one dare not put them into a steam-pipe direct because, if the least drop of water got on to the fine platinum coil, it became short-circuited and there was an end of the thermometer. He had spoiled many thermometers in that way, and had found it necessary in using them for getting steam temperatures to put them in a very thin metal envelope, which would absolutely prevent water getting on them. Wire gauze was not good enough. The envelope gave them naturally a slight lag, a lag which would be quite impracticable with temperatures varying as quickly as gas-engine temperatures varied. He would be very glad if Professor Burstall would state what his own final opinion was, as to the extent to which measurements of temperatures taken at the very low power fairly represented measurements of temperature taken at full load—whether he thought the differences due to the greater number of explosions per minute were very important or not.

When the Report first came into his hands he read it with considerable trepidation, because some thirteen years ago he had made a good many gas-engine experiments which were published at the time, and somewhat talked about. At that time he believed that they were the most complete experiments which had been made, or at any rate published. He ventured at that time on a calculation of temperatures at different parts of the stroke. The Callendar thermometer was a thing which did not then exist, and very many of the arrangements which Professor Burstall had used were also non-existent, for the excellent reason that probably he himself had not had the cleverness to work them out: even if he had, he had not the money nor the opportunity, and had to do without them. He was, therefore, not a little anxious to compare some of his old experiments with Professor Burstall's to find out how far they agreed or how far they would have to be rejected as totally antiquated, and he felt no little satisfaction in finding that they corresponded uncommonly well. It was a little difficult to pick out one which corresponded throughout with one of those in the Paper, but he found that the Crossley engine, which was tested at the Society of Arts trials in 1881, compared in many points at full power with Professor Burstall's experiment B 4; that was, it had a ratio of air to gas of 6·9 as against 7·4, and it had a clearance volume of 0·4 as compared with 0·45. Of course it was a much bigger and a more economical engine. It had an efficiency of 22 per cent. as against 20, but that was not a very great difference. The four temperatures came out somewhat as follows: B 4 was 347° C. (page 1064) for the end of compression, and his calculation for the Crossley was 320° C. The maximum temperature in B 4 was 1,668° C. (page 1065) as against 1,670° C., and at the end of the expansion it was 942° C. as against his calculated 910° C. So that clearly his figures could not be very wrong, and he hoped he might say the Society of Arts trials were probably substantially right. In one respect, however, there had been obviously a mistake—in the question of the variable specific heat. His own calculations made out in every case except one that the combustion was complete at the end of the stroke. It did not make out that it was always complete at maximum temperature, and he thought Professor Burstall had come to the conclusion that it practically was. There was one trial in which he thought he found that combustion was not complete, even at the end of the stroke. This conclusion was arrived at from the form of the expansion curve, working on the assumption of uniform specific heat. But, as Professor Burstall said, the conclusions derived from a given curve were very much altered when that assumption was rectified.

With regard to Appendix VII (page 1083), the Table which showed the effect of change of compression, he did not think conclusions should be too hastily drawn from that Table. As it stood he had no doubt every figure in it was right, but if the comparison were made from another quartet of trials, there would be somewhat different results. Anybody who was sufficiently interested in the matter would find it very useful to make other similar tables out of A, B, C, and D. What had been done was to take one trial out of each of the four sets, A, B, C, and D, taking four trials which had about the same ratio of air to gas (in Table VII somewhere from 10½ to 11), so that they might be comparable, and then with each such set there were trials to be compared with four different compressions. When he was going over the Table the other day, he took another set of four, namely, A2, B2, C3, and D1, all trials with a

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ratio of air to gas of about 6·7. He would not trouble the members with any detailed comparison, but looking at the heat balance percentages column headed I.H.P., it would be found that the results varied quite differently from the Table. With the 10·5 air-to-gas ratio, the efficiencies rose continuously from A to D, namely, as the compression increased. The differences were quite marked:—18·9, 21·2, 21·9, and 23·1. All that this showed, however, was that with the particular ratio of air to gas chosen, there was an increasing efficiency with an increasing ratio of compression. But taking another set equally comparative, namely, the four he had mentioned, the efficiency figures became 17·4, 18·7, 18·2, and 18·1 respectively, so that there was no such rise in the efficiency as in the other case. There might be some special explanation for that, but he thought the fact of the matter was simply that all the circumstances of the case must be considered, and that the ratio of air to gas had a considerable effect on the efficiency with different compressions. The whole of the figures were given in the Tables so clearly, that anyone could pick out any sets and make a complete comparison; and he was very glad that Professor Burstall, whom he congratulated greatly on his work, had been able to put the figures so fully before the members.

The President said it would aid the discussion if Mr. Bryan Donkin would at this point describe the Mathot continuous-pressure recorder, of which examples were to be seen in the room.

Mr. Bryan Donkin, Vice-President, asked that before describing the instruments he might be allowed as a Member of the Committee to make a few remarks on the excellent Report, which was a monument of labour, patience, care, and skill. It was quite true, as Dr. Kennedy had said, that the experiments had been made on a rather small engine, but there was great hope of having a much larger one if only the funds of the Institution would allow of the continued expense for the tests. The compression of the charge of air and gas was one of the chief points of the Report, and details were given with four different compressions. Great care had been taken to make all the results as reliable as possible, and Professor

Burstall had had much experience in making experiments. In all accurate trials it was very important to avoid misfires, because they altered the composition of the charge inside the cylinder, the ratio of air to gas, and the power, as shown by the indicator diagram if taken just after the misfire. It was the first time that any series of reliable tests had been made of the temperatures at different parts of the stroke after the explosions, and this, the most interesting part of the Report, had evidently given Professor Burstall much trouble. The maximum temperature seemed to be in the neighbourhood of 2000° C., which was extremely high. It was extraordinary how well gas-engines worked even at such temperatures. Another new and very instructive point was brought out, namely, that even with the cyclonic action of the explosion and the very short period—a fraction of a second—during which each explosion lasted, the gases seemed to be very much cooler nearer the internal cylinder walls. The centre of the cylinder was some 200° C. hotter than the part quite near the walls. The only way to take such temperatures was by means of the platinum thermometer, and to avoid breaking the very thin wire it was necessary to work the engine with many misfires and at a very low load. It was a point which had to be carefully considered in reasoning on the temperatures, that they were not even made at one-quarter, or one-half, or at full load. In the future it was hoped that, by means of some device, temperatures might be taken with one-quarter or half-load, and such results would be still more interesting than those given. The platinum wire was only about 1-100th of a millimètre in diameter.

He was sure the Committee valued the labours of Professor Burstall, and he thought the members who had studied the Report would appreciate the time and pains he had spent in preparing the interesting tests and Tables. There were many diagrams of interest, but none giving a complete temperature diagram during a cycle, and he hoped Professor Burstall would be able to prepare one for the Proceedings. The temperature lines were only drawn during expansion, and for the rest of the cycle they were given in figures. He wished to know the exact position of the thermometer in the clearance space. He was sorry Professor Burstall had not been able to give any entropy diagrams; one or

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two would be very desirable. With regard to the experiments of the First Report, the maximum heat efficiency per I.H.P. was then 21 per cent., whereas 23 per cent. had now been reached.

The two recording pressure instruments shown were the invention of a Belgian engineer, M. Mathot. They belonged to Mr. Dugald Clerk, who had kindly lent them for that evening. The object of these useful instruments, Figs. 12 and 13, Plate 184, was to record on moving paper, driven by a clock, the various vertical lines of pressure and vacuum in a gas or oil-engine cylinder during a certain time—in the case of Fig. 12 two minutes. In this way the maximum pressures of compression, explosion, exhaust, and suction were all shown on paper, as well as the number of explosions, the misfires or "cut-outs," with the corresponding number of revolutions of the engine.

The instrument consisted of an ordinary indicator provided with a water-jacket and a pencil marking the pressures on a continuously moving band of paper on a time base; another fixed pencil gave the atmospheric line. The water-jacket to the indicator-cylinder, Fig. 13, prevented it getting too hot from the high temperature of the gases in a similar way as the water-jacket to the motor cylinder. The speed of the moving paper was such as to separate the different lines indicating the various pressures. In practice this recorder had been found very useful in showing faults in construction of motors, such as bad working or leaky or insufficient area of the various valves for the air, gas, &c.; also the excessive length or area of the gas, air, or exhaust pipes or passages. After their modification or adjustment much greater power had been obtained. All the pressures during one or many cycles could be recorded on the Paper, and at different speeds of the motor.

The charge of gas and air should be admitted to any motor cylinder, and discharged therefrom at *minimum* pressure. The explosion should be at *maximum* pressure so as to obtain a *maximum* power. Variation in the compression pressures could also be studied. All these could be recorded on the paper and with different loads on the engine. Figs. 14 to 21, Plates 185–6, gave with explanations examples from actual gas or oil-engines taken by means of this instrument.

Professor Richard Threlfall pointed out that in the Report (page 1053) it was stated that the finest wire employed in the platinum resistance thermometer had fused after a few explosions. Now the melting point of platinum could hardly lie below 1,700° C., a much higher temperature than any recorded. It might be argued that the platinum absorbed carbon at the high temperature to which it was exposed, and that this lowered the melting point; but against this view it was to be remembered that the absorption of carbon by platinum was not instantaneous, nor was there any evidence that the melting point of platinum was in fact materially lowered by the carbon which it might take up. In addition to this, the temperatures measured had been found to appear higher, the thinner the wire. Everything seemed to point therefore to the probability of the measured temperatures being too low. It was quite evident that metals with higher melting points than platinum would have to be used.

With regard to the calculated temperatures, it appeared from the calculations of Le Chatelier * that in the case of carbon-dioxide, at all events, the high pressure prevented there being any serious amount of dissociation. The method of calculation adopted appeared therefore to be sound from this point of view. Returning to measurements of high temperatures, it was pointed out that the thermo-couple, though electrically less sensitive than the resistance pyrometer, had the great advantage that it could be much more easily repaired, and it might be used exactly as the author had used the resistance instrument. To do this, all that was necessary was to close the circuit of the couple through a potentiometer by means of the rocking key, just as was done for the resistance instrument.

In order to obtain sensitiveness the wire could be used in the form of thin strip, this being of course protected, except just where it was exposed to the temperature in question. Mr. W. H. Steele, in a Paper read before the Royal Society of Victoria in 1893, described some experiments in which he had found large electro-

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* Zeitschrift fur Physik. Chem. II. 1888, page 782.

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motive forces generated in wires (supposed to be homogeneous), when unequally heated. The speaker had not had an opportunity of examining this effect, nor had he seen any corroboration of Mr. Steele's results by other workers, but it was a matter which should be considered by any one using a couple of the kind described.

With regard to the small size of the experimental engine, no apology was needed. In order to elucidate thoroughly the details of the action of a gas-engine, it was important to investigate the effect of varying the relation of the volume of the active gases to the area of the cooling surfaces to which these gases were exposed, and this necessitated trials with at least two engines, one large and one small. It was also necessary to establish the experimental methods on a firm basis, and this could be done more cheaply and quickly in a small engine than in a large one. It was to be hoped that, when the experiments were extended to larger engines (these engines would be really larger, that is, would have larger cylinders—150 H.P. was the size mentioned), this 150 H.P. was to be got out of one cylinder.

The author expressed surprise at the variable temperatures observed in the cylinder. The speaker could not see that this was a matter for surprise; the influence of the cylinder walls must of necessity be felt; but even setting this aside there was every reason to suppose that the gases were in a state of violent motion during the explosion, and this motion was turbulent. Consequently the pressures and temperatures would vary locally throughout the mass. Some very interesting high speed photographs were obtained by Von Oettingen and Von Gernet (Wiedemann's Annalen of 1888) of the explosion of a mixture of oxygen and hydrogen in a tube, the explosion being rendered luminous by the addition of the dust of copper salts. These photographs illustrated very well the complex nature of a gas explosion.

Referring to the indicator diagrams and the remark made as to the desirability of obtaining entropy diagrams, he pointed out that this would be difficult, seeing how arbitrary the selection of the temperature would be.

During the discussion of Mr. Humphrey's Paper,* the speaker drew attention to the curious increase in the work required to pump the charges, as the velocity of rotation of the engine increased. He suggested that this might be due to the gases becoming hotter in the passages of the admission valves the faster the engine ran, and consequently having their viscosities increased. Calculating on this basis, he concluded that to make the explanation valid the gases would have to be heated to 140° C. at the higher speeds. This calculation referring to a larger engine could not of course be insisted upon, but it was at least curious that the present trials had given a practically identical value. The relation of the viscous properties of gas to the working of the gas-engine was a comparatively open field, in which research could hardly fail to yield results of interest.

Discussion on 1*st November* 1901.

Professor Hugh L. Callendar, in continuing the discussion, said it was with great pleasure he took the opportunity, so kindly afforded him by the Institution, of saying how very much he appreciated the work which was being carried out by the Committee, and particularly the work which Professor Burstall had been doing on the gas-engine with regard to the measurements of temperature, a work he had been carrying on for the last five years or more. He thought all the members would agree it was a Report of very great importance, and, so far as he had been able to read it, he thought it was one that positively bristled with controversial points. He was sorry to say his professorial avocations had not left him nearly the time he should like in order to study the Report, and to get at the bottom of all the valuable evidence which it contained; but looking at it superficially it struck him that the important point studied for the

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* Proceedings 1901, page 237.

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first time perhaps with success was the effect of the walls of the cylinder of the gas-engine on the cycle. One could now see how the cooling effect of the walls modified the elementary theory of the engine, and was able to form some sort of estimate how far the temperatures calculated from the pressure of the gas observed with the indicator really agreed with the true temperatures, and how far the temperatures varied at different parts of the cylinder. He himself had made an experimental study of a similar difficulty in the theory of the steam-engine. The condensation of steam on the walls of the engine had been always one of the great difficulties, concerning which many writers had tried very hard to formulate some rational theory. There was one point at the commencement of the Report which illustrated in a very prominent manner the difficulty of allowing for the effect of the walls. It would be noticed that for the first time, at any rate in an English Paper, some of the results had been calculated allowing for the variation of the specific heat of the gases —the products of the explosions—in the cylinder. This method of calculation made a great difference in the results obtained, but the values taken for the specific heats, for which formulae were given (page 1040), were, he thought, extremely doubtful. The method of experiment employed was closely analogous to the explosion which was taking place in the gas-engine itself. Explosive mixtures were fired in a closed cylinder 7 inches high by 7 inches in diameter, and the maximum pressure was read by means of a Bourdon gauge, and from that, knowing the amount of heat and knowing the temperature, it was possible to calculate the average specific heat of the gaseous mixture. That was a very simple and ingenious method, and the results of those experiments by Mallard and Le Chatelier were undoubtedly of the highest interest, but he thought they were extremely doubtful for the very reason he had mentioned. It was almost impossible to say, in an experiment like that, how far the cooling effect of the walls of the cylinder modified the real temperature of the gas, and he thought that the correction for the cooling effect could not be accurately applied, although the authors attempted to do so in the best way at their disposal. Possibly in consequence the specific heats obtained were a good deal too large. The specific heat of carbon di-oxide deduced from these experiments was more than three times as great at 2,000° C. as it was when measured at the ordinary temperature. A good deal of that apparent increase might be due to the cooling effect of the walls, and not be a real thing. The temperatures were under-estimated, very possibly owing to an insufficient allowance being made for the cooling effect. The difficulty of the experiments would be realised when he mentioned that in one of the experiments, where the explosive mixture used consisted of hydrogen and oxygen in their combining proportions, the condensation was so rapid that the pressure fell from 5 mètres of mercury down to atmospheric pressure in one quarter of a second. In that time, or in an exceedingly small fraction of that time, the highest temperatures had to be measured, and it had to be assumed that the pressure gauge followed the explosion so accurately that it enabled one to deduce the law of cooling, so as to apply a correction and obtain the highest temperature reached in the explosion. He mentioned that to give some idea of the danger of placing explicit reliance on the values of specific heat obtained in that way. The particular formulæ given in the Report did not exactly agree with the results of those experiments, particularly in the case of steam. The experiments gave, he thought, rather higher results than the formulæ given in the Report. Probably the formulæ were more correct than the experiments, but he thought the formulæ were very doubtful. As Professor Burstall had said, perhaps they were the best that were to be had at the present time. They were made a long time ago, and he was sure it was desirable they should be repeated.

There were a good many very important points in the Report needing discussion, but as he did not wish to take up too much time he would confine his remarks chiefly to the question of the measurement of temperature, of which he had had more experience than in the actual testing of gas-engines. He had done some work, but only in an amateur sort of way as one did at College, in the testing of gas-engines, and he could not pretend to be an authority on that part of the subject. With regard to thermometry, it might be within the knowledge of some members of the Institution that he

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had made a number of experiments himself very closely analogous to those which had been made on the gas-engine by means of very delicate thermometers, the results of which were communicated to the Institution of Civil Engineers a few years ago, and discussed at one of their meetings.* Those experiments he undertook in the year 1895, about the same time that Professor Burstall undertook his first experiments on the gas-engine. He was not at that time aware of Professor Burstall's experiments, so that he attacked the problem quite independently, and the apparatus used was a good deal different. He was working on the steam-engine while Professor Burstall was working on the gas-engine. One of the most obvious points of difference in the experiments was in the construction of the thermometer used for measuring the temperature of the steam. He exhibited one of the thermometers used in the work, the particular thermometer which had been attached to the middle of the piston of the steam-engine, and worked backwards and forwards through the steam for about a month. So long as it was inside the cylinder of the steam-engine, where the workmen could not get at it with hammers, pliers, spanners, or anything of that sort, the thermometer survived all right. Although made of glass it would stand the steam being turned straight on to it, and the knocking about of the steam did not break the fine wire; but afterwards he used the same thermometer outside the engine in a tube in getting the temperature in another part of the cylinder, and then the outside end of it very soon got broken, although the remainder of it had survived. He indicated the construction of the thermometer by means of Fig. 24. There were four leads of thick platinum wire fused into a glass tube at both ends, A and B. In the middle of the tube there was a sort of constriction C formed by melting in the glass, so that it was very thick at that point. Then the leads came out at the other end of the glass tube, and were connected on to the wires which went to the measuring apparatus. Two of the leads were called compensating leads, and were used to eliminate the effect of change of resistance of the connecting wires. The constriction C was fitted into a gland, the object of the constriction being to prevent the steam pressure from blowing the thermometer out of the hole. The thermometer was held very firmly by asbestos packing pressed round the constriction C. The delicate wires on which the measurements of temperature depended were attached at the end A exposed to the steam. There was a loop of wire 1–1000th of an inch in diameter and about 1½ inches long, and on the compensating leads there was another loop about half the length or less, to eliminate the effect of conduction in cooling the ends of the fine wire. He had the actual thermometer present at the Meeting with the original wires, and if examined with the lens the wires could be easily seen. That thermometer had stood exposure to steam for a long time, although it was made of glass with platinum wires fused through it. It had been necessary to use glass in these experiments, for the sake of getting the joint perfectly steam-tight and maintaining perfect insulation between the wires. He could not have used the mica and asbestos insulation employed by Professor Burstall, because that would have become wet, and the insulation would have been damaged. The rest of the experiment was very similar to Professor Burstall's arrangement, but he used a contact-maker different to that employed by Professor Burstall in 1895, but very similar to the second form of contact-maker which was described in the present Report. It was rather more complicated, because he wished to be able to provide for a number of different contingencies which did not occur in the gas-engine experiments. In the steam-engine experiments there were several difficulties absent, difficulties which occurred in the gas-engine. In the gas-engine the temperatures to be measured were much higher, and that, of course, made it necessary to employ a stronger wire. The explosion was doubtless more

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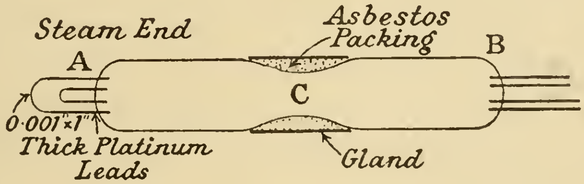
* Institution of Civil Engineers, Proceedings 1897–98, vol. 131, page 147

Fig. 24.



(Professor Hugh L. Callendar.)

violent than any motion of the steam, and for that reason also it was necessary to use a stronger wire. He had been able to use wire 1–1000th of an inch in diameter, while Professor Burstall had not been able to use wire finer than 1·5 or 2-1000ths of an inch.

Another difficulty that occurred in the gas-engine was the danger of the wire becoming contaminated with carbon, particularly if illuminating gas containing heavy hydro-carbons was used. In that case, if there was not sufficient air to burn all the carbon, the platinum wire might be contaminated with carbon. As one of the previous speakers had suggested, the carbon might make the wire rather more fusible, so that it might give way more easily. In thermometers of the kind he mentioned, the most important condition to satisfy was the condition of very great sensitiveness. The thermometer must work extremely quickly, so as to be able to measure the temperature with advantage. That was even more important in the gas-engine where the speed was so high. In the steam-engine he did not use a speed of more than 100 revolutions, whereas in the gas-engine he believed Professor Burstall used about 120 to 200 revolutions, and perhaps he might have succeeded in getting measurements even at higher speeds than that. It would be understood that there was but a very short time in which to measure the temperature, and for that reason it was important to use an exceedingly fine wire—the finer the wire the better. He observed that one of the previous speakers had suggested the use of strip instead of wire. That would undoubtedly be an advantage in one respect, but, on the other hand, it was so very much weaker than wire, and presented a so much larger surface to the rapid currents of gas that he was afraid it would very quickly get twisted and broken, so that it would be of no use. He had never used strip himself, but from his experience with wire that would probably happen, and a reliable thermometer would not be obtained. There seemed to be no doubt from Professor Burstall's experiments and his own with the steam-engine that fine wire was quite quick enough, that one could obtain reliable measurements of temperature, and that the wire did not lag too much—it did lag somewhat, but very little behind the temperature of the steam or the temperature of the exploded gas.

Roughly speaking, it might be worth while to mention that the quickness varied inversely as the section of the wire (not as the diameter, but as the square of the diameter), so that a wire 1-1000th of an inch in diameter would be four times as quick in getting the temperature as a wire 2-1000ths of an inch in diameter. That was perhaps the first and most important condition,—the condition of quickness. Another important point, which he thought was hardly mentioned in the Paper, was the question whether the wire ever reached the actual temperature of the exploding gas owing to the *error of radiation.* That was a most important error. The wire was being heated by the gas, but all the time it was losing heat by radiation to the sides, so that quite apart from all question of quickness a wire would probably never reach the actual temperature of the gas; it must be always cooler than the gas. It was a very important question as to how great that radiation error was—how much hotter was the gas than the wire on account of the loss of heat by radiation. The wire would reach a stationary temperature, when the loss of heat by radiation was equal to the gain of heat by conduction and convection; the conduction gain must balance the radiation loss. He used the word "conduction," but of course convection also played a part. That might be roughly put in symbols in the following way. Supposing there was a coefficient of conduction C, that the heat gained by conduction was proportional to the difference of temperature between the wire and the gas; let θ_1 be the temperature of the gas or the flame, and θ the temperature of the wire; then the heat gained by conduction, $C(\theta_1 - \theta)$, must be equal to the heat lost by radiation. It was known that, in the case of a bright platinum wire, the rate of loss of heat by radiation varied very nearly as the fifth power of the absolute temperature; that had been established in experiments by Petavel and Paschen, and a number of observers who all obtained fairly consistent results, so that on the other side of the equation could be written the heat losses by radiation proportional to the difference between the fifth powers of the absolute temperatures of the wire and the sides of the cylinder. If θ represented the temperature of the wire on the absolute scale, and θ_0 that of the walls, the radiation loss could be

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represented by the expression H $(\theta^5 - \theta_0^5)$, and the equation would be

$$C(\theta_1 - \theta) = H(\theta^5 - \theta_0^5).$$

H was a constant coefficient which did not depend on the temperature. C, on the other hand, was a coefficient which depended on the temperature and pressure in a manner which was not accurately known. Having that equation it would be seen that it was extremely important, working at high temperatures in gas-engines, to make sure that the radiation loss was not too large compared with the conduction coefficient. It was necessary to make the radiation losses as small as possible compared with the gain of heat by conduction, so that the difference of temperature between the wire and the gas might be as small as possible. It would be seen how extremely important that became at high temperature, when it was realised that the radiation losses varied as the fifth power of the temperature. In his steam-engine experiments he was working at low temperatures, and that was not a very important question; but he took the precaution a year or two before starting the experiments to make some experiments on the point, comparing the radiation losses with the conduction losses in the case of fine platinum wires, and he found that in the temperatures which he was going to use in the steam-engine the radiation loss was from 50 to 100 times less than the conduction losses, so that the error from radiation in those experiments probably did not exceed a few tenths of a degree at the outside; and it was possible in those experiments to measure the temperature with certainty to one or two-tenths of a degree at some points of the stroke, even with the engine running as fast as one hundred revolutions per minute. In the gas-engine the difficulty was very greatly increased. It was not possible to use very fine wires because, as the author had explained, they became fused by accidental high temperatures in the explosion. No doubt there were great variations of temperature in any explosion, and with a fine wire part of the wire might easily get fused by some excessively high local temperature. That was a point which Professor Burstall had brought out very clearly,—that the temperature which occurred in the explosions in the gas-engine were really very much higher than the temperatures calculated from the average pressure of the whole of the gas. It might be naturally concluded that they must be much higher, because it was possible to fuse a fine platinum wire in the cylinder of the gas-engine. It might not be within the knowledge of all the members that it was possible to fuse fine platinum wire in almost any gas-flame quite easily, provided that the wire was fine enough. In an ordinary gas-flame a wire of about 2-1000ths of an inch in diameter could be fused fairly easily. A wire 1-1000th of an inch in diameter would fuse almost instantly, proving conclusively that the flame was really above the melting point of platinum. He thought Professor Burstall's experiments also conclusively proved that temperatures above the melting point of platinum, 1,800° C., occurred in the working of the gas-engine. There was another advantage of using fine wire, which he had not mentioned, which was closely connected with the reason why a very fine wire would melt, whereas a thick wire would not melt. It would be said naturally that the reason why the thick wire did not melt was that the heat was carried away so quickly by conduction, but that was not the whole truth. Even if the thick wire was suspended by fine wires, so that the heat could not be carried away by conduction, it would still not reach the same temperature as the fine wire. If the two wires—a thick wire and a fine wire—were put together in the flame, it would be found that the fine wire always became very much hotter than the thick wire. To illustrate that particular point, Professor Callendar placed two platinum wires—one 6-1000ths of an inch in diameter, and the other 4-1000ths of an inch in diameter—together into a porcelain tube, and connected them differentially with a recording instrument, Fig. 22, Plate 187, to show the difference of temperature between the wires. When the two wires were heated together in the porcelain tube, the indication of the apparatus to which they were connected did not vary. But when directly exposed to the flame, the finer wire became about 60° C. hotter than the other. He mentioned that he used a similar instrument in recording the variations of temperature in the working of the steam-engine, "temperature-cycles" as he called them, and he had

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also used the same instrument for recording cycles of voltage and current in alternating circuits.

He thought the apparatus might be interesting, as it was the actual apparatus he had used in a great many of the experiments. The fine wire reached a much higher temperature under the same conditions when exposed to a gas-flame than the thick wire, because the coefficient C was very much greater for the fine wire in proportion to the coefficient of radiation H. The coefficient of radiation depended only on the surface of the wire, and therefore was proportional to the diameter, whereas the coefficient of gain or loss of heat by conduction was very much greater for the finer wires in proportion. The greater the value of the ratio C/H, the less the error obtained in measuring the temperature with a wire in that way, where it was exposed to radiation error. Very fine wires could not be used in these experiments on account of their liability to fuse, but it was still possible—and that was the point he wished to explain—to measure the temperature of the flame by means of wires which were too thick to fuse, which did not fuse because the radiation kept them below the temperature of the flame. By the formula he had given, it was possible to calculate how much they were kept below the temperature of the flame by using two wires of different sizes, by measuring the temperature of the flame with a wire four mils. in diameter, and with another wire six mils. in diameter, knowing the way in which the coefficient C varied with the size of the wire. It was found by experiment and also theoretically that the ratio C/H for very fine wires varied nearly inversely as the diameter of the wire. Knowing that, it was obviously possible to calculate the temperatures by means of that formula, even if the temperature was above the fusing point of the wire. It had been suggested that it would be necessary to measure the higher temperatures with fine wires of higher fusing point. He did not think there was any wire that would be more suitable than platinum for that purpose. It was not possible to make a wire of iridium, as it was far too hard, and he thought the same was true of the other pure metals that had fusing points above that of flames. There were some alloys of platinum and iridium which might be drawn, but which were very difficult to draw if the fusing point was much above that of platinum. He thought it would be practically impossible to draw wires of those metals which would be fine enough to be of any use. If, instead of having a pure metal, an alloy was used, it would be very unsuitable for that particular method of measuring temperature, owing to its small and variable change of electrical resistance.

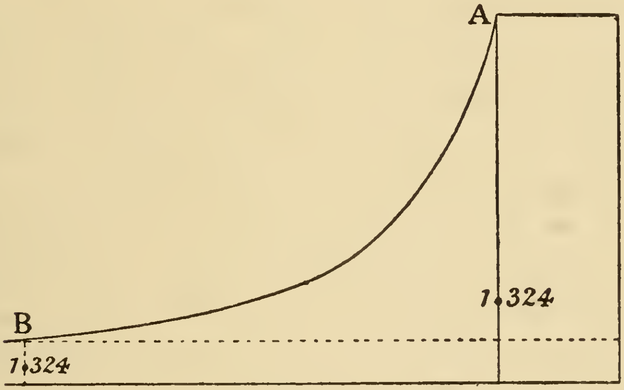
He wished to say a word or two about the possible use of the thermo-couple in such experiments, which had been suggested by one of the previous speakers. No doubt it would be possible to use a thermo-couple if it was made of sufficiently fine platinum wire, combined with platinum-rhodium or platinum-iridium, and utilised as a thermometer to measure the temperature in the same way as the instruments he had described. But there would be the great disadvantage, that the power available for measuring the temperature in that way would be ten to fifty times less than the power available in the electrical resistance method. That was a very great difficulty. One required all the power one could possibly obtain, and if it was possible to get more power one would be glad to have it in order to make the measurements more accurate. The great difficulty was that the contact with the galvanometer was only made for a very small fraction of a second, so that the power available was very much diluted. There was another slight disadvantage also, namely the variable size of the junction, where the two wires of the couple were fused together. He thought it would be necessary to fuse them together, although they might be twisted; but the junction would be larger than the rest of the wire, and it would be difficult to apply any calculation as previously explained in order to reckon out what the true temperature was. It was only possible to apply that calculation by knowing accurately the diameter of the wire used, and the law by which its temperature deviated from the actual temperature of the gas. It had been mentioned by a previous speaker that the great advantage of the thermo-couple was the ease of repairing it when it was broken. That was perfectly true. But it was also very easy to repair a platinum thermometer, if one knew how to do it. He thought Professor Burstall would agree with that.

(Professor Hugh L. Callendar.)

In working on the steam-engine he had had a large number of thermometers broken, particularly the fine wire, and he had very frequently to repair it, and always found it an easy thing to do. After repairing the wires, it was only necessary to measure the resistance cold before starting, and then one was ready to get the temperatures as before. It was not necessary to take the ice point, the steam point, and sulphur point every time a new thermometer was made, because the properties of pure wire were so absolutely uniform, that it was possible to calculate the temperatures without going through that process every time. The real use of the thermocouple in the experiments, it appeared to him, was quite different, namely, the determination of the instantaneous temperatures of the walls, and the amount of heat which was absorbed by the walls of the cylinder at different points of the stroke. It was for that purpose he had used the thermo-couple himself in his experiments on the steam-engine, and he thought it was fairly successful in determining how much heat was absorbed, and how much condensation took place. It was a very difficult thing to do, because the power available with a single thermo-couple was so extremely small, but the thermocouple was admirably adapted in other ways for that particular experiment. It gave the temperature at an exact depth in the wall of the cylinder; it also gave the instantaneous value of the temperature at an exact point of the cycle, and from that, by observing the temperature at different parts of the cycle, it was possible to calculate the amount of heat the metal was absorbing. The metal would also give valuable evidence in the working of the gas-engine. By calculating the heat absorbed at any point of the stroke it would be possible to work out the heat balances more satisfactorily than was possible without that knowledge. Of course the experiment would be very troublesome and difficult, and it would be necessary to use a galvanometer about one hundred times as sensitive as that used by Professor Burstall. It would be a difficult galvanometer to work with in the immediate neighbourhood of a gas-engine, but still, if the experiment could be done, he thought the results would be extremely valuable. He wished to recommend that to the consideration of the Committee. The other point on which he wished to lay particular stress was the point with regard to measuring the actual temperature of the gas by using wires of different sizes, and applying a knowledge of the way in which the radiation error affected the temperature of the wire.

Mr. J. Macfarlane Gray wished to take the opportunity to put the fractional indices of adiabatic expansion, which were given on all the diagrams, in another light than that in which they were generally regarded, so that they might be intelligible to even the non-mathematical mind. He took one of them $PV^{1\cdot324}$ constant. The usual reading is "the pressure multiplied by the 1·324 power of the volume is constant;" or what amounted to the same thing, "the specific heat at constant pressure is 1·324 times the specific heat at constant volume." Neither of these definitions caught on to the mind of the practical man. What mental conception was begotten from the expression "the 1·324 power of a volume"? If, however, the diagram be drawn as in Fig. 25 with the 1·324 as shown, it could then be read as expressing that, calling the area of the complete diagram out to infinity 1·324, then the area of the peevee rectangle for any point A is the ·324, and the rest of the diagram is the 1. This is true for any point on the curve, say, for B; the rectangle there is also ·324 of the rest of the diagram formed by the curve carried out to infinity. It must not, however, be supposed that this relation expressed a property of the gas; it was a property of the mathematical curve only, and this particular curve with index 1·324 approximately agreed with the actual diagram.

Fig. 25.



Professor David S. Capper wished to endorse the vote of thanks which had been given to Professor Burstall, and to express his admiration for the way in which the experiments summarised in the Report had been carried out. He had had the privilege of being present, when Professor Burstall carried out some of the earlier experiments referred to at the time when the experimental engine was at King's College, and he could speak from his own experience of the marvellous way in which the difficulties as they presented themselves were met by Professor Burstall, and the marvellous accuracy with which both the calibration of his instruments and the experiments themselves were carried out by him. There was therefore no doubt in his mind that the work described in the Report constituted a real addition to their knowledge of what went on in the cylinder of a gas-engine. Perhaps the questions on which the most striking light had been thrown by the Paper were amongst others those of "after-burning," the effect of compression on economy, and the temperature variations in the cylinder. Taking first the phenomenon of "after-burning," which had always presented a difficulty in gas-engine heat-balances, he would refer to a trial of his own which had been published some years ago, which exemplified what he wanted to say upon the point. This trial was the first, he believed, in which calculations of the temperatures after explosion were based upon the exhaust analysis, that is to say, in which values for the specific heats were obtained from an analysis of the exhaust products for calculating the temperatures after explosion. The temperatures, etc., obtained by calculation in that trial on the imperfect knowledge then available, were remarkably close to the figures which Professor Burstall had obtained by the more refined methods which he had originated.

The Table on the next page showed the comparison with one of Professor Burstall's trials.

In calculating out the temperatures during the expansion curve, he had found that, even after allowing for the more accurate specific heats obtained from the exhaust analysis, there was still an apparent addition of heat during expansion of something like 5 per cent., which had, in default of a better explanation, to be put down to

	Professor Capper's Trial, 1895.	Professor Burstall's Trial, B 4 (p. 1064.).
Ratio : $\frac{\text{Clearance volume}}{\text{Cylinder volume}}$ . . .	0·42	0·45
Compression . . lbs. per sq. inch	69·7	71
Revolutions . . . per minute	172	196·2
Explosions . . . per minute	84·7	87·1
Per cent. of full power	98·4	89
Suction temperature . . C.°	32 (calculated)	135 (measured)
Compression temperature . C.°	480	347
PV^n; value of n	1·37	1·359
Maximum temperature . . C.°	1500	1668
Exhaust temperature . . C.°	1047	942
Mean pressure . lbs. per sq. inch	60·3	63 1
Mechanical efficiency	0·87	0·75

"after-burning." He supposed that very few authorities, if really pressed upon the point, would maintain that "after-burning" actually took place in a modern gas-engine. He had always felt some degree of uncertainty in referring to "after-burning" as a fact, and yet that the expansion curve did really rise above the adiabatic was such a persistent matter as to force one to explain it somehow. Now he thought that Professor Burstall, if he had not finally settled the matter, had at any rate hinted at an explanation of this apparent phenomenon, which he for one accepted as in all probability the true explanation, namely, that the specific heat of the gases was not constant but varied. He had worked out what would be the result if the values of the varying specific heat given by Professor Burstall were taken into account in his own trial above referred to; and he found that the whole of the apparent addition of heat during expansion disappeared, and a balance was obtained showing loss to the jackets during expansion instead. This to his mind was from a common-sense point of view almost certainly much nearer to the true facts of the case than the hypothesis of "after-burning."

He did not suppose that Professor Burstall would maintain that the values of the varying specific heat had at all satisfactorily been proved to be those quoted by him, and he hoped Professor Burstall would be able to determine at some future time what their value really was. But in suggesting this he felt some diffidence, for the

(Professor David S. Capper.)

experiments Professor Burstall had already undertaken covered such a wide ground that, even if all the points suggested to Professor Burstall for elucidation were actually solved by him, he feared it would be a long time before the results would be forthcoming. He most sincerely wished for him the long life which would be entailed by the solution of so vast a problem.

With regard to the remarks Professor Kennedy had made last week, he had thought (perhaps somewhat audaciously) of attacking him with regard to his attitude towards Professor Burstall's use of the metric notation for expressing his results. Professor Kennedy had taken as an instance the difficulty of thinking in "kilogrammes per square centimètre," but he himself thought that this was perhaps a somewhat unfortunate illustration, as he had always felt "kilogrammes per square centimètre" as his one prop and stay in the translation of their system into the metric, because one kilogramme per square centimètre was so very nearly atmospheric pressure. But in working out the trial he had referred to, and in trying to use the formulæ quoted in the Report (page 1041), and at the same time translating from the English into the metric system, he had found so much nerve-trying difficulty that he really did wish that Professor Burstall had found it possible to give his results in both systems of units. He feared that the value of Professor Burstall's work might be somewhat lost sight of in this country from the mere difficulty of comparing his results with previous work by former experimenters.

With regard to the influence of compression upon economy, it did not seem to him—he thought Professor Burstall would be the first to agree with him—that the experiments described in the Report had at all conclusively shown the influence of compression on economy. In Appendix VII (page 1083), as had already been pointed out by a previous speaker, the instances given for comparison referred to trials with a more or less constant ratio of air to gas; but if a different selection of trials had been made, it would be found that the results did not at all coincide with those shown in Appendix VII. It appeared to him therefore that it was necessary to investigate a good deal further into the whole of the conditions under which each set of experiments were made, before it was possible to draw any absolute conclusion as to the effect of increased compression upon the efficiency of an engine.

With regard to the variation of temperature throughout the cylinder, it was a matter of supreme importance that Professor Burstall had been able to show by direct measurement that this temperature did vary from point to point of the cross section of the cylinder. It was very remarkable that he had found so large a difference, as he mentioned, between the temperature close to the cylinder walls and the temperature of the centre of the cylinder. This fact, which as he believed had been here conclusively shown for the first time, although many authorities had previously assumed such a variation to exist, was one which had a very important bearing upon the efficiency of the gas-engine, for it affected not only the problem of the influence of the water-jacket upon economy, but it also affected the question of how far the efficiency of the engine depended upon the ratio of air to gas, and the richness of each expansive charge in the cylinder.

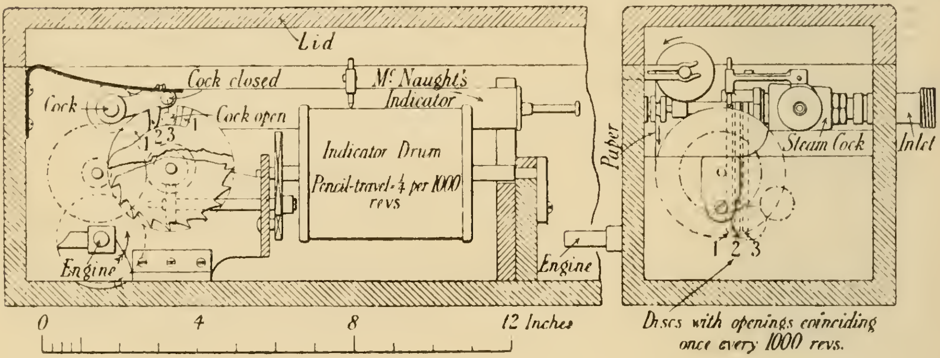
Another point upon which Professor Burstall had laid stress was to his mind perhaps more important than any, and that was that at present the gas-engine only used about a third of its possible thermal range compared with the 70 to 80 per cent. of its possible range which steam-engines used; and he himself felt that future improvements in the gas-engine probably depended much more upon improved methods of utilising the thermal range than upon questions of increased compression, or even upon saving some of the heat thrown away in the jackets. It was therefore towards a utilisation of the total temperature range in the gas-engine that effort ought in his opinion to be more largely exerted, because in that direction lay the possibility of further increasing the efficiency of the gas-engine, and that that could be done was to his mind an absolute certainty.

Mr. Arthur Rigg made some remarks in reference to the diagrams shown by Mr. Donkin, because he thought they were applicable both to gas-engines and other engines, and were not strictly a matter concerning gas-engines alone. In 1859 he made

(Mr. Arthur Rigg.)

what was called an intermittent indicator, Fig. 26, which gave diagrams more or less akin to those obtained from the instrument Professor Callendar had shown. It was made to take one diagram every thousand revolutions of an engine, by means of a ratchet apparatus working three discs running at different speeds. The engine was an old-fashioned throttle-valve beam engine with a 34-inch cylinder and 6 feet stroke, making 18 revolutions per minute, and driving millstones for grinding white lead at Messrs. Walker, Parker and Co.'s Works at Chester. There was a suspicion that the men did not feed the stones properly at night, and the object of the indicator was to find this out. The consternation of the men, when they discovered that by means of the innocent little box it was known what they had been doing at night, was a spectacle to see.

Fig. 26.—*Diagram of Intermittent Pressure Recorder*, 1859. (*Rigg.*)

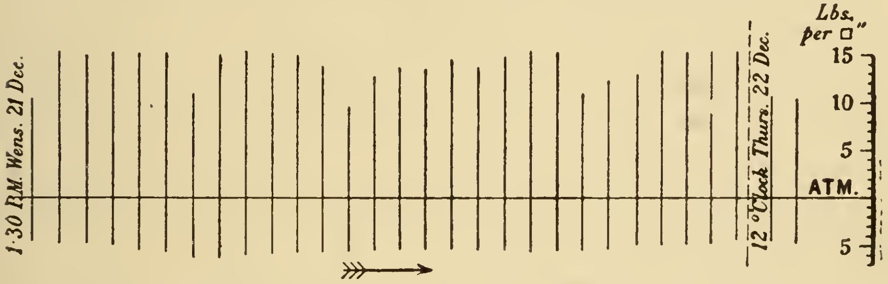


This indicator was so designed as to admit pressure from the cylinder of the engine for and during one revolution for every 1,000; and as the average speed of the engine was 18 revolutions per minute, the intervals were at about 55 minutes apart, so by marking one spot on the endless paper band it was easy to find out the times when anything of special note occurred, for the diagram gave the steam pressure and vacuum as determined by the governor, etc. A McNaught indicator, with scale $\frac{1}{10}$ inch = 1 lb., had its pencil resting upon the paper web generally at the atmospheric pressure line: the paper web travelled about ¼ inch for every 1,000 revolutions of the engine, and a steam cock opened by a spring was provided for the purpose of admitting or shutting off pressure from the indicator. The engine drove a ratchet which turned three discs lying alongside each other at different speeds. In each disc a piece was cut away in the form of a cam, so arranged that at intervals of 1,000 revolutions the three cams coincided underneath the spring steam cock, which at once opened and admitted pressure or vacuum and made the recording mark. Immediately after this the quickest moving disc closed the cock; the second disc then held it shut, and finally the third performed that office until another 1,000 revolutions had been made.

Mr. Rigg exhibited the original apparatus made in 1859; he also explained its mode of working and showed indicator diagrams, Fig. 27, which the apparatus had taken.

Fig. 27.—*Intermittent Pressure-Recorder*, 1859. (*Rigg.*)

24 hours' work, less about 30 minutes' stoppage for oiling.



Mr. W. C. Goodchild thanked the Institution for allowing him to attend its meeting as a visitor, and expressed his regret that he was not able to be present at the previous meeting, and therefore might run the risk of repeating something which other members had said. The first point on which he required some information was the arrangement of the valve settings. It made a difference in the Otto cycle engine at which point in the stroke the exhaust valve opened. The compressions in these tests were different, and it was not necessarily better to have a constant setting of the valves. In his own experience he found it possible to increase the power of the engine considerably, by opening the exhaust valve about one-tenth earlier in the stroke, that is, at 0·75 or 0·8. A diagram showing the angles of the crank at the different positions of the valves would

(Mr. W. C. Goodchild.)

be very useful, and it would be also as well to know whether the angles were constant in all the different tests, or whether any variation was made in them. Secondly, he wished to mention the question of the variation in the mechanical efficiency of the engine. Great care had been taken in all the experiments, and no doubt special care was taken to see that the rope-brake tests were correct; but at the same time it was possible that with a larger engine, an engine more in accordance with present-day practice, a direct-coupled dynamo of known efficiency would give more reliable results than a rope brake, and he suggested, if the experiments were being continued, that point should be taken into consideration.

With regard to Appendix VII (page 1083), Professor Capper had mentioned one of the points he was going to refer to, namely, that the chosen tests A7, B9, C7, and D8 did not really show the true relation between the compression and the thermal efficiency. No doubt from a research point of view the Table was very accurate, but from the practical point of view, what was wanted was the greatest amount of power with the best economy, and it would be found in most cases in the tests the maximum amount of power possible was not being obtained from the engine.

[Professor Burstall here explained that the engine was working loaded, with no missed explosions.]

An engine of a certain cylinder dimension was designed to give so much B.H.P. as a commercial engine (not as an article of research), and would generally work at that load. He would suggest a comparison should be made between the tests quoted (page 1083) and some of the other diagrams which gave a greater temperature range. It would be found that in A7 the temperature range in the cylinder was only 288° C. while the B.H.P. was 2·72. It was misleading to take this test as a standard of comparison. With the same compression, in A4 the B.H.P. was 3·55. It was reasonable to say that if the engine was capable of doing 3·55 B.H.P., that would be its nominal load—it would be used as an engine of that H.P. rather than the lower H.P. The temperature range in that case was 447° C., and the thermal efficiency on the I.H.P. was very slightly less; but on the other hand the cubic feet of gas

TABLE.—*Abstract from Appendix* VII.

Trial No.	B.H.P.	Mechanical Efficiency.	Best Thermal efficiency on		Temperature range C.°	Ratio: air / gas.	Cubic feet of gas per B.H.P. Hour.	Compression Kg. per cm².
			I.H.P.	B.H.P.				
			per	cent.				
A 4	3·55	0·80	18·7	15·0	447	8·6	30·9	3·98
A 7	2·72	0·70	18·9	13·2	288	10·6	34·9	4·32
B 3	4·07	0·86	19·4	16·7	645	7·2	28·2	4·92
B 9	2·51	0·66	21·2	14·0	351	11·4	33·5	5·36
C 5	3·66	0·79	20·0	15·8	474	8·7	28·6	6·59
C 7	2·45	0·61	21·9	13·4	337	11·0	34·1	6·52
D 5	3·51	0·72	22·7	16·3	530	9·2	27·9	8·7
D 8	2·81	0·69	23·1	15·9	345	11·9	28·5	8·36

(Mr. W. C. Goodchild.)

per B.H.P. came out at 30·9, whereas in the test quoted it was 34·9. Although that was giving a much better thermal efficiency on the I.H.P., yet it was using 4 cubic feet of gas more per B.H.P.-hour, and that was the commercial side of the question. Again, referring to the same diagrams, A4 and A7, it would be found that the compression was 3·98 kilogrammes per square centimètre in the first test, and 4·32 in the second test. From a perusal of the Tables, he thought it could be seen that the thermal efficiency did rise with the compression, if calculated on the I.H.P., and therefore in the present case it was naturally concluded that the extra 0·2 per cent. in thermal efficiency was due to that extra compression, and he thought it better not to compare Tables A, B, C, D, on this basis. To mention the others, B3 and B9, the temperature range in one case was 645° C. and in the other 351° C. One used 28·2 feet of gas per B.H.P.-hour against 33·5, so that it was giving away 4·5 cubic feet of gas just for the sake of having an extra 1·8 per cent. of thermal efficiency on the I.H.P.

With regard to the question of minimum gas-consumption, it would be found that in each of the Tables there was a test other than the one quoted, which gave more economical results, and by looking at the Table (page 1123) it would be seen that whereas for the A compression the thermal efficiency on the I.H.P. was 18·7, for the B compression 19·4, for the C compression 20, and for the D compression 22·7, all less than the maximum, yet on the B.H.P. the thermal efficiency was better, particularly with the lower compression. In other words, the tests A4, B3, C5, D5, which gave the best thermal efficiencies on the B.H.P., used the least cubic feet of gas per B.H.P.-hour.

The Tables also showed that within certain limits moderately rich charges and lower compressions were quite as economical as higher compressions with very weak charges. The figures for thermal efficiency on the B.H.P. in B compression were 16·7, and in D compression 16·3. It was actually less with higher compression, taking the thermal efficiency on the B.H.P. and not on the I.H.P. In this case—B3—the temperature range was 645°, and the mixture rich. The engine would give a good output for its size.

There was one point in favour of moderate compression; not only was there less tendency to pre-ignition, but with a moderate compression the engine itself did not cost so much. One question he would like to ask was whether the compression was altered by the junk ring or packing pieces on the crank end of the connecting-rod.

Professor Burstall said that A and B were by packing pieces, and C and D by the junk ring.

Mr. Goodchild said he asked the point because, if a junk ring was put on the back end of the piston, it was not known to what extent the radiating surface was altered. The cooling surface at the front end of the cylinder, namely, the piston itself, was a constant quantity, but if a thick plate was put at the back it would alter the amount of radiation at that end; and, unless the piston was a water-cooled piston and the same thickness of lining was used all the time, he did not see the value of troubling about a few degrees one way or the other, when there was such an unknown quantity as this radiating surface.

With regard to the construction of the engine, before coming to the meeting that evening he looked up the First Report of the Committee,* and he noticed that the air inlet was adjacent to the exhaust outlet. He did not think there was a modern engine of any standing in which the exhaust and the air inlets were adjacent. The thing to do was always to keep the air inlet as cool as possible, some even going so far as to put it on the opposite side of the cylinder to the exhaust. That might account for the high suction temperatures shown in the tests. He understood that Birmingham gas was used in the tests, and he thought it was a fact that at Birmingham carburetted water-gas was mixed with the ordinary coal gas, and that would account for the very low calorific value which was about 550. Most lighting-gas in large towns was 600 or 640 B.T.U.

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* Proceedings 1898, page 209.

(Mr. W. C. Goodchild.)

With regard to pressures, he took it that the Tables 3 (pages 1064, 1070, and 1076), under the heading of compression, gave the pressures in kilogrammes per square centimètre, and also in pounds per square inch in absolute measure, but the word absolute came only under the one heading.

Professor **Burstall** said that was so.

Mr. **Goodchild** said he also wished to know whether it was possible, working with producer gas, to utilise the temperature range better. With coal gas of high calorific value giving high initial temperature, there was an increase in the losses to the water-jacket, but with producer gas the temperature was naturally lower to start with, and probably that also of the exhaust; and it was quite possible that the temperature range would show a larger proportion of the whole utilised in the engine. He would like to know whether experiments were going to be made with producer gas or other cycles than the Otto cycle?

Mr. W. **Worby Beaumont**, while thanking the author of the Report for the information placed before the members, and congratulating him upon the ability displayed and the great trouble he had taken over the Report and experiments preceding it, could not help admitting that a large part of all the last speaker had said was deserving of confirmation. It was a pity from the first that the experiments had not been made with a gas-engine of, if not more, modern design, at all events worked under modern conditions, and, with all due respect to those who had been making the experiments, worked by those who could get the best results from the engine; because, however carefully the results of the experimental working of an engine were shown, however carefully they might be observed, and however carefully the composition of the products of combustion might be taken, together with the other figures, the whole of the value of these results depended on the way in which the engine, as a tool, using certain materials for its operations, had been used. The reporter had given a tremendous quantity of materials, but had not done very much in the way of drawing conclusions, allowing the members to draw them for themselves as far as they could. The materials in a sense were very valuable, but there were numerous points in connection with gas-engine economy, which made him wish the reporter had a newer engine and possibly worked by those who made it. The author said (page 1042) that "Some of the heat energy however does pass out, being converted into kinetic energy of the exhaust. To estimate this amount, the charge in the clearance space has been supposed to expand adiabatically from exhaust pressure to the pressure of atmosphere; the change of internal energy due to this expansion has been taken as the heat lost by the residue to exhaust." The figures relating to this were given, and it was admitted that there was a mere nothing resulting, but even as it was the results were only valuable when they were taken with regard to an engine constructed like the one here used. The statement did not include any reference to that loss of energy which might come about through defects or through circumstances not only relating to *relative position* of the air and exhaust valves, as mentioned by the last speaker, but also to the *sufficiency* of the air and exhaust valves and passages for the different conditions, and especially if the engine was running at any speed at all. The amount of that energy so absorbed would vary, and did vary with other causes of loss of efficiency. The reporter stated also that the loss to the jacket—referring to Dr. Slaby's test—was much larger than in his test, and modern gas-engines owed their improved efficiency mainly to a reduced wall loss. The reporter left it to the members to go through the Tables and diagrams, to see how it was that the improved efficiency was obtained by those reduced wall-losses. How did the reduced wall-loss come about now as compared with the engines of sometime since? It was difficult to gather from the figures that that was the case. It appeared that the further statement of the reporter's with regard to the compression was open very much to question, where he said that the gain due to compression was not as much as was commonly supposed; and the reporter went on to say (page 1043), "For many reasons very high

(Mr. W. Worby Beaumont.)

compressions are not desirable, and the reporter wishes to draw attention to the fact that at present gas-engines are only utilising about one-third of their total temperature range, when working under best conditions, while in steam-engines more than three-quarters of the temperature range is utilised." This was a very misleading comparison, and did not justify the statement that the gas-engine was not utilising the high temperatures employed. It was not utilising the higher temperature in the sense that the whole range of that temperature was represented when an engine was dealt with purely from a thermo-dynamic point of view; but when it was looked at from a thermo-chemical point of view, it must be admitted that the high temperature was being utilised. If it were not utilised, there would not be the high rate of combustion necessary to get the best results when using the high compression—best for the most economical consumption of fuel in the form of gas. The thermo-dynamic relation in that sense between the steam-engine and the gas-engine was a misleading comparison. In one sense the experiments had been good, in that they had stuck to one subject. The speed had been practically one speed throughout the whole time, and only one thing, namely, compression had been varied with variations in the strength of the mixture; but one would like to suggest that, if Professor Burstall intended to continue the experiments, one of the most important things to enter upon would be the effect of very much higher speeds than he had been using for the experiments. The higher speeds with higher compressions and higher pressures were necessary to get some really practical notion of the value, not only of the higher initial pressures, but of the higher temperatures and the value of rapid expansion proper to them and the higher compressions. On such points, in order to get the full value from the figures given, certain other experiments should be carried out on the lines of the modern tendency with regard to gas-engines. An engine that was using even the poor gas employed, approximately 30 cubic feet of gas per B.H.P., must be either doing very badly, working under bad conditions, or, taken with the varying mechanical efficiency mentioned, must in some way or another be certainly unsuitable for containing figures of any value as indications, at all events to those who were to make steps in advance in the construction and working of gas-engines beyond what had been already reached. He suggested that the Institution might, without very much more expenditure on printing, manage to get some of the Tables printed, so that when people looked at, say Table 8, they could, without all the trouble of hunting back to Table 4 or 3 or 7 and trying to remember the figures from one to another in their relation, be able to read them right across, so as to see such things as mechanical efficiency, brake power, and indicated power and the consumption of gas in their proper sequence. These figures might be given in English figures instead of in a mixture of British and metric measurements. If the Tables could be made more handy, they would be more appreciated. He would be the last to make any remarks in disparagement of the way in which the engine had been used for experimental uses. But when new experiments were made, if the experiments were to be continued, he would suggest that the members did not very much want to see what could be obtained when a gas-engine was run so as to see how badly a gas-engine could work.

Mr. W. C. Goodchild drew attention to the fact that the piston speed used in the tests appeared to be about 400 feet per minute. It was the practice to run something over 800 feet per minute.

Professor Burstall said that, for the purpose of shortening his reply as much as possible, he would answer the speakers not in the order in which they made their remarks, but mainly according to the natural grouping into which the questions fell. Mr. Beaumont commenced by telling him that he (the reporter) did not know how to run a gas-engine, but exactly where Mr. Beaumont derived that information he did not know. Mr. Beaumont could never have seen him run a gas-engine, and he thought it was a gratuitous assumption on his part that professors did not know how to run gas-engines quite as well as the gas-engine makers. He knew better than anyone that the engine was not the best engine that could have been used for the purpose, but he would like to point out that it was the only engine that could

(Professor Burstall.)

be used for the purpose. Certain of the leading gas-engine firms in this country were approached, and asked either to lend or sell an engine for the purpose of making the research, and they declined. It was therefore necessary to take the best engine that could be obtained, and the remarks which had been made to show that the engine was not up to modern practice or anything else were quite beside the question. Either the experiments had to be made on that engine or not at all. As certain members seemed to be anxious as to what would be done in future, he might say that the experiments henceforward would be made on an engine of the most modern class that could be possibly obtained, and of a size—150 H.P.—that would put their minds quite at rest as to whether it was commercially efficient or not. But that could be only done because at the present moment, through the generosity of an American citizen, the University of Birmingham was able to expend a large sum on its engineering department.

A considerable amount of criticism apparently, both expressed and implied, had been made on the question of the metric units. He explained how those metric units arose: the instrument was partly graduated in the metric system and partly in the English system, and when the results came to be worked out he naturally wished to work them out in both units; the Tables in that case would have taken up a large amount of space, and the conversion would have involved a great increase in the rather lengthy calculations. If anyone went through the calculations on the English system, he thought they would agree with him. It was impossible to work complicated mathematical expressions in the English system, without running serious risk of errors. That was the whole explanation. He had no particular love for the metric system, but he did prefer to save his brain from the useless labour which was involved in the English system of units. He hoped that engineers would try more and more to work to what was after all a very simple system.

Some of the other points that had been raised had been partially dealt with, but he would like to say a little about what Professor Callendar had said on the temperature measurements (page 1106).

The members had naturally had an explanation of the temperatures from the master hand himself, and he felt extremely dubious of saying anything on a subject where he was approaching one who had made it his life's study. He himself was an engineer, and had only taken the temperature measurements up as they seemed to touch engineering problems. He certainly was not aware of the interesting point which had been raised with regard to the relative loss between radiation and conduction. He had always considered that conduction was greater than radiation, but he could quite see that it was possible, that at high temperatures the radiation might be an important factor. He was well aware that the thermometers were lagging the whole time, and it would be noticed that the temperatures were never quoted until one-tenth of the stroke had been completed, the reason being that he could never measure the initial temperature. By that time the wire was so far behind, that the temperature was quite absurdly low, 1,000° cr 1,100° C. (1,800° or 1,980° F.). He had looked upon it only that the wires were following the temperature with a constant, or not quite constant, lag behind. He had endeavoured to determine that lag, but without success, and he could not say that the temperatures were the actual temperatures of the gas. The temperatures were the temperatures of the wire. It was possible that Professor Callendar's remark about connecting the two wires might be utilised. He had himself used platinum-iridium wires which he had drawn down to 1-1000th of an inch, and the melting point was certainly very considerably higher. Professor Callendar would know exactly the reason why he did not use them in the experiments, because he did not know what their readings meant on the temperature scale. At some future time he hoped to determine what they did mean, and to utilise such thermometers for the measurement of the temperatures which would be probably obtained in the new gas-engine. He had not continued it on the present one, because those temperatures were not of great service in furthering the theory of gas-engine work.

Mr. Goodchild had spoken about the valve setting (page 1125), which was kept constant, the exhaust valve being open at 95 per cent. of the stroke. The mechanical efficiency of the engine was variable,

(Professor Burstall.)

and he confessed he did not particularly mind or trouble about mechanical efficiency. It was not, from a research point of view, of very great importance; as regards the experiments they were conducted purely on research lines. They served as a sort of opening up for experiments made on a large scale, and therefore he did not particularly trouble about the mechanical efficiency. Mr. Goodchild would doubtless be pleased to know that the new engine would be direct coupled to a dynamo, and the load would be thrown on by artificial resistances. The alterations in compression were partially done by packing pieces on the big end of the connecting-rod and partially by a junk ring. The junk ring was not a desirable way, but it was the only way of doing it at that particular time. The temperature measurements were purposely made on an engine without any junk ring whatever, and therefore they applied to any particular kind of engine. There was no cooling action of the wall introduced by the junk ring in the temperature experiments. With regard to the inlet valve, he confessed he was not in agreement with Mr. Goodchild; he was going to put the inlet valve of his new engine quite close to the exhaust valve. He was not going to make any effort to put it close, but he did not see any special objection, unless Mr. Goodchild referred to the scavenging, which would be done by other means. In a large engine no one would ever dream of using coal gas. The coal gas used in a gas-engine was much too costly, and he hoped everybody who used gas-engines in future would not think of considering coal gas, but would simply use producer-gas as a matter of course. It was not intended to conduct experiments on any other than the Otto cycle, as that cycle was the only one which was of any commercial importance. The Table which had been objected to in Appendix VII (page 1083) was merely a Table to assist members in comparing the efficiency of the engines at different compressions. Of course the efficiency would vary according to the compression and according to the ratio of air to gas, and he did not think that that Table, or any other Table, showed very conclusively that the efficiency rose rapidly or even to a small extent with the compression; he put it in just as an assistance.

He had drawn no conclusions, for very obvious reasons, because he did not wish to do so at present, recognising that those conclusions could only be drawn when dealing with the larger plant. The variability of specific heat, which had been alluded to by Professor Callendar, was a most important point. He quite agreed with Professor Callendar that the results were not at all accurate. The experimental error was probably considerable. But he had to use some figures, and therefore used the best he could obtain; he trusted at some future date to repeat the experiments on the variability of the specific heat with a Callendar thermometer, and in that way to eliminate the cooling action of the wall. But the gas-engine experiments were enormously long; the few experiments shown in the Report had occupied his spare times for four years, and as his life was not altogether made up of gas-engine experimenting, he was not able to do perhaps as much as he would like to do.

He confessed he did not quite follow why Mr. Beaumont (page 1128) objected to his stating that the gas-engine as a thermodynamic machine was bad. It did not utilise the range; it threw its exhaust products out at a comparatively high temperature, whereas the steam-engine threw its products out at about 100° C.; and the fact that the actual amount of energy which was utilised in the gas-engine was larger than in a steam-engine was simply because of the high temperature. But looking at it as a machine for turning heat into work, it was not doing as well in its own way as the steam-engine was doing in its way. Surely if it were as good, there would be no steam-engines whatever; whereas as a matter of fact steam-engines were running on, not a coal consumption, but a cost consumption very little worse than that of the best gas-engine. When it was considered that the steam-engine had at most a thermal efficiency of some 18 or 19 per cent., whereas 36 per cent. could be obtained from the gas-engine, he did not think he was so wrong in stating that the gas-engine had not reached the same pitch of perfection as the steam-engine had done at the present day. With regard to running the gas-engine as badly as it could be done, in making research one must not always work at maximum efficiency.

(Professor Burstall.)

Where experiments had to be made, an engine had to be tested under varying conditions, so as to find out the influence of changing a particular factor.

The President, in his opening remarks (page 1089), made a statement which he thought was extremely valuable, namely, that the work dealt, so to speak, with the anatomy of the gas-engine. He had dissected it, perhaps wrongly, but still made an attempt to dissect it, and he would like to tell the members that the experiments were the only series of experiments under varying conditions that had been made in a gas-engine. There were no other published experiments, as far as he was acquainted with the subject, in which more than half-a-dozen experiments had been made on the same engine. That was why they were valuable. Whether the engine was good, bad, or indifferent did not matter in the least; there was a series of experiments on the same engine under varying conditions. The next task would be of quite a different nature, namely, to find out what were the directions in which efficiencies in gas-engines were to be improved. Up to the present, experiments had been simply made on an engine under very fixed conditions, and now it would be necessary to consider the question of governing gas-engines, whether by throttling the air and gas or by the hit-and-miss system. The question also had to be considered of the mixing of the air and gas by a mixing valve, as was done in the Westinghouse, or by some other contrivance, and also it was necessary to consider the effect of scavenging or non-scavenging. Those were the points of future research, together with the determination of the temperature in an engine whose cylinder was absolutely symmetrical. At the risk perhaps of having to retract his own words, he would like to say that having finished those experiments he had come to the conclusion—although he was not a gas-engine maker, and he hoped he would be excused as an amateur making any statement about such points—that in a gas-engine there should be no boxes, nor unnecessary parts; there must be some holes for the valves, but there should be no pockets in the side nor anything of that sort. The valves should all work in the back. In that way one would have a cylinder which had the minimum of surface for the maximum of volume. It might be that

that method was perhaps quite wrong from the gas-engine maker's point of view. He thanked the members for having listened to the Report.

The PRESIDENT thanked Professor Burstall for the excellent reply he had given to the discussion. This discussion had been a prolonged one, and had brought forward many interesting points which would be of great assistance to the Gas-Engine Research Committee in their future work. He was quite sure that all the points so raised would have the fullest attention given to them by the Committee, who were most desirous to make the work they were carrying on of use to every maker and user of a gas-engine. In addition to thanking Professor Burstall, he had also to thank the Royal College of Science, and particularly Mr. Merrett, for the loan of various thermometers which were exhibited and which could be examined after the meeting. He also had to thank the makers of the Junkers' calorimeter for the example of that instrument which they had shown. (*See* Fig. 23, Plate 187.)

Communications.

Mr. JOHN JOHNSTON wrote that he wished to utter a protest against the use of the metric system of units in the Report, particulaly as it was the system of least value to British interests, and also as he had not found it and did not believe it to be superior to their own system of units; in his business he found it necessary to work in both systems to suit Continental trade. He considered it worth while working out the Tables in British units, although it might involve a little additional labour. Like other speakers he was somewhat astonished at the results tabulated in Appendix VII (page 1083) of the Report, as he had always found and believed that higher compression in a gas-engine gave a correspondingly higher explosion and consequent higher maximum temperature, but there

(Mr. John Johnston.)

he found the opposite tabulated. With a compression pressure of 3·75 atmospheres a maximum temperature o 1,145° C. was obtained, and with a pressure of 8·44 atmospheres a maximum temperature of only 1,094° C. was obtained; this was a truly astonishing result, and the opposite of what should be. A disturbing factor however in this Table, which took away the whole of its value, was that in none of the trials had the same ratio of gas to air been maintained.

Professor Burstall in his concluding remarks had said that he knew that the temperatures registered were not the actual temperatures attained; if that were so, why did he go to all the trouble of making trials and giving results known to be incorrect? It would have been better to spend a few years experimenting with and improving his apparatus, until it would give a correct result. With regard to the position of the thermometer for taking the temperatures, he had good reason to believe that if, instead of fixing it in the combustion chamber, it had been fixed in the piston head, as Professor Callendar explained he had done with the steam-engine, a different result would have been registered. The writer spent a good many years experimenting with an impulse-every-revolution gas-engine and had constructed two different classes of engine. In one the exhaust point was at the combustion-chamber end of the cylinder and in the other it was at the forward end, being over-run by the piston before the end of its forward stroke. In the latter case the temperature of the exhaust gases was always lower than in the former, though the pressures registered were practically the same in both cases. In the latter case the ports were the shorter and more direct of the two, so that they could not account for the lower temperature. While mentioning this class of engine, he would be interested to know why Professor Burstall so emphatically declined to consider experimenting with any class of engine except the "Otto cycle" engine. He had said that it was the only engine of commercial importance (page 1132), but the writer thought that was no reason. He would say the question was, "Is it likely to remain the only engine of commercial importance?" and in answer he would say, "No, if further improvement is to be made"; he knew of one member of the Committee who thought as he himself did on this point.

From a study of the indicator diagrams he would say the gas and air were not sufficiently well mixed in the cylinder, and he would be interested to know if a mixer was used in the inlet port, as many makers did not trouble to fit them. He had seen several engines made from bad-working into good-working engines by the simple addition of such a device.

Professor **Eugen Meyer** wrote that, without going more fully into the meritorious work of the author, in which temperature measurements in the interior of the cylinder were of special interest, he would like, with reference to the remarks (pages 1044–5) as to the most perfect gas-engine, to suggest a cycle which appeared to the writer the most suitable one for comparing with the real cycle of a gas-engine. He wrote about it in the "Zeitschrift des Vereines deutscher Ingenieure," 1899 (Experiments with a gas motor).

The chemical composition, the temperature, and the pressure of the total charge consisting of fresh air, fresh gas, and the residue of combustion in the compression chamber at the end of the charging stroke were well known, and the volume of said charge was equal to the volume displaced by the piston plus the volume of the compression chamber. Let them assume that this total charge was adiabatically compressed to the volume of the compression chamber, that at this volume it burnt completely, and that thereupon it expanded adiabatically until the piston reached again the dead point, and that at this large volume it cooled down again to the temperature at which the charge was pumped in, and that then it was replaced without any loss by a new charge. The above described cycle would really take place in the engine if no heat were lost to the walls, if the combustion were always perfect, and if it always took place at the inner dead point (which, according to the teaching of thermodynamics, was the most favourable for four-stroke motors), that is, if there were no losses through delayed and incomplete combustion, and finally if there were no losses through the exhaust. The cycle in question would therefore correspond to a four-stroke

(Professor Eugen Meyer.)

motor without any losses. If the mean pressure of the cycle without losses was compared with the gross mean pressure of the real diagram, the difference between the two would give the loss of pressure (and consequently of power) produced by the tardy and incomplete combustion by the action of the walls and the advance in exhaust. This was a point which ought to be of the greatest interest for the designer, for by changing the design he could reduce this loss and thus increase the consumption of gas.

Different mean pressures were of course obtained for the engine working without any losses, according as the specific heat of the gases was assumed constant or, according to Mallard and Le Chatelier, as varying with the temperature. The writer found, in numerous experiments with engines working with lighting gas, that the gross mean pressure of the real diagram was about 70 per cent. of the mean pressure of an ideal engine working without any losses, if the calculations were made assuming constant specific heat, and about 87 per cent. if the calculations were made with the values given by Mallard and Le Chatelier. Accordingly 30 per cent. in one case and 13 per cent. in the other of the work of the ideal engine must be considered as lost.

Herr Max Münzel wrote that the classification of the excellent results of these trials, together with the corresponding diagrams represented, in respect to the engine tested, were extremely valuable and instructive material for study.

On referring however to the First Report of the Gas-Engine Research Committee, the writer found reason to doubt whether the object of the trials had been attained in such a way as to correspond with the present conditions of gas-engine construction. He could not agree with the reason given for using a small experimental engine.* The relations of the surfaces and volumes of the charging chamber were essentially altered by the size of the engine, because the first increased as the square, and the latter as the cube of the linear dimensions, and therefore the exchanges of heat with the walls doubtless became more difficult.

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* Proceedings 1898, First Report, page 210.

Since the publication of the First Report, the conditions of gas-engine construction had changed greatly. At the present time gas-engines of 1,200 B.H.P. were running, and, owing to the continual increase in the use of electricity, small gas-engines had in many places, in towns and in the country, been superseded by electric motors. To this result the fact had not a little contributed that large gas-engines in conjunction with Dowson, blast-furnace, or other cheap power-gas furnished a source of power at a less cost than any other class of heat motor. Therefore, if the means permitted, it would be extremely desirable to repeat the experiments which have now been so well carried out on a small engine, in exactly the same way on a large engine, having a cylinder diameter of at least 20 inches with 30 inches stroke. These tests should not be confined to lighting gas, but should include some with the now frequently used power-gas, Dowson gas, water gas, carbonic-acid gas, etc. The quantity of gas used could be easily and conveniently measured not for half-an-hour only, as in these trials, but for any given length of time, by using two gas-holders, one being re-filled, while the second was connected to the engine.

The construction of the experimental engine was not free from objection, and did not correspond with what was now required in a good gas-engine. The exhaust valve was placed so low that the lubricating oil was easily blown out with it, and thus, unless the piston was continually lubricated, it would run dry and the friction be increased. On the other hand, if very much oil be supplied to the cylinder it would be vaporised, and cause the power developed by the small engine to appear higher than actually corresponded with the quantity of gas admitted.

To determine the real value of the mechanical and the thermal efficiency (page 1083), data respecting the construction of the lubricator and the drops of oil supplied per minute would be very desirable. It was just these efficiency-values which in small engines might vary considerably with the amount of lubricating oil used.

With magneto-electric ignition, as now almost universally adopted in gas-engines on the Continent, no difficulty was experienced in

(Herr Max Münzel.)

isolating the high-pressure spark. In these apparatus an electric current was generated by induction in a wire coil oscillating between two magnetic-rods. During the greatest strength of the current the closed circuit in the interior of the cylinder was interrupted by a contact-lever with oscillating motion, and the spark thus generated fired the charge in the cylinder. No stuffing-box was needed, because, in consequence of the high pressure prevailing in the cylinder, the oscillating lever was forced with a rebound against a metal casing. The moment of ignition was determined by a small crank attached to the valve shaft, which caused the induction coil to rotate by means of compressing and automatically loosening a spring. By slightly altering the position of the crank, the moment of ignition could easily be varied. For isolating the different parts, mica plates were found to answer excellently.

In the ignition arrangement adopted in the experimental engine, the danger was that the two relatively thin 3-inch steel rods which projected into the cylinder might become red hot and produce premature ignition. This difficulty was increased, because the rods were not placed in the current of the newly admitted charge, and therefore were not cooled by the fresh air drawn in at each stroke.

It was stated in the Report that this method of ignition worked faultlessly for two years. It must be remembered however that this statement applied to isolated experiments each lasting a short time; had the total working time been stated in hours, it would have afforded a more accurate test of the utility of the arrangement. Upon the above grounds the writer did not consider that this method of ignition could be employed for prolonged or continuous runs lasting say a week, such as were now often usual on the Continent in large gas-engines. In short trials lasting only half-an-hour it was probable that, with this small engine, premature ignitions did not occur.

With regard to the valve gear, the writer was of the same opinion as Mr. John Fielding.* Means having now been found, even in an ordinary four-cycle engine, to work at light loads quite as economically without cutting out ignitions as with misfire valve-gearing (hit and miss), the aim of the gas-engine constructor should be to get rid of the "hit and miss" system altogether, and to build only engines which drew in gas and air in equal proportions for all loads, and worked with less compression when running under light loads. With this method tube ignition was not suitable, because when running empty or at light loads it gave irregular diagrams. On the other hand, with electric ignition at any load, and with gases of high or low heating value, the writer had obtained excellent diagrams, both as regards the consumption of gas and regularity in running. This method of varying the quantity of the charge admitted had the advantage that engines working thus could be used without alteration to generate electric light, and did not require unduly heavy fly-wheels. As in practical work an engine often ran under a load below the maximum, it would with valves on this principle work at lower compression and lower initial pressure the moment the load was reduced. Such a system saved wear and tear to the engine, and its "life" was prolonged.

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* Proceedings 1898, First Report, page 265.

He did not find in the Report data regarding the speeds of the gas, etc., through the exhaust, admission, and gas valves. It would have been very desirable if, when the maximum and minimum limits of variation had been determined by practical experiments, it had also been shown how far the dimensions of these valves could be reduced. It also seemed that, in the experimental engine no special value had been attached to obtaining a thorough mixture of the charge of gas and air, although if the two were well mixed it had always an advantageous influence on the economical consumption of gas.

In Appendix VII (page 1083) an endeavour had been made to show the effect of variations in the compression, which could not for the following reasons be taken as representing a standard for general application. To vary the compression by altering the length of the piston-rod, and chiefly by the addition of a mass of metal on the piston, gave much more unfavourable results than if the size of the compression space itself, having regard to the smallest possible wall-surfaces, were varied. According to the writer's own experiments such an addition to the piston, as used in the experimental engine,

(Herr Max Münzel.)

had an especially injurious effect. By taking up a large portion of the heat of combustion, and by the permanent heating produced in the cylinder, it acted harmfully upon the amount of gas and air drawn in, and often caused premature ignition. For this reason a plate or other piece of metal on the piston should, as far as possible, be avoided. It was probably impossible to make a comparison between the efficiencies at high and low speeds, unless previous arrangements were made, by the use of a heavy fly-wheel, to obtain the same uniformity in the movement of the piston at either speed. One should be content with smaller valves for the slower speed engines.

To study the method of coupling a gas-engine direct to a water pump running at less speed, the writer had, taking count of what had already been said, made comparative experiments, and found that with a single-cylinder engine running at a normal speed of 200 revolutions per minute, the consumption of gas at maximum power per B.H.P. was 5 per cent. higher than when running at 80 revolutions. The engine ran without misfires, with varying composition of the charge, and on the usual four-cycle system.

To determine the quantity of air required for combustion and the best compression, he had always found a Junkers' calorimeter of the greatest service. Without knowing the exact chemical composition of the gases, he had ascertained that the most advantageous degree of compression stood in a certain definite relation to the heating value of the gas, as determined by the Junkers' calorimeter. To clear up this point, a thorough study of a large gas-engine would be of value. The best proportions of gas and air for any given engine could be easily determined by placing a throttle-valve in the air-admission pipe, and regulating the opening until the smallest consumption of gas for the highest power developed had been attained. The range of temperature might be utilised to a considerably greater extent if the gas-engine were combined with the waste-heat engine invented by Professor Josse of Berlin. The heat carried off from the engine by the water-jacket and the high temperature of the exhaust gases might be utilized to generate vapour of carbonic-acid gas, to drive a steam-engine coupled direct to the gas-engine. The writer hoped to return later to this newest method of utilizing the waste gases from a gas motor. Finally he ventured to propose that all measurements of gas should be based on a temperature 0° C. All other temperatures of 12° or 15° were more or less arbitrary; but if 0° C. were taken as the standard, it was easy to calculate the volumes for any other temperatures. It was now usual on the Continent, when testing the maker's guaranteed consumption of gas in these motors, to calculate it from the actual temperature and pressure of the test to the standard pressure of 760 mm. and 0° C. temperature, and for a given (lower) heating value.

Mr. A. Rollason wrote that he had read with great interest the Second Report to the Gas-Engine Research Committee, and appreciated the labour which had been expended in carrying out the experiments there recorded, which to the writer's mind were of considerable value to all interested in the construction and working of gas-engines. These experiments confirmed the results observed in actual working of engines of various powers. The records given of the temperatures and pressures in the small engine experimented with would be practically the same in the larger sizes, with this exception, that the heating effects would be more marked as the size of engine increased, especially if the products were retained in the clearance.

It had been the tendency in recent years to increase the compression by reducing the clearance and the volume of products retained therein. Indicator cards, Trials A, test 5; B, test 6; C, test 5; and D, test 4, in which the ratio of air to gas admitted was nearly the same, showed that, by reducing the clearance and increasing the compression when the products were retained, there was a corresponding increase in the temperatures in the engine. The cards showed a higher thermal efficiency, increasing with the compression, but the brake efficiency was lower, the higher pressure being at the commencement of the stroke and unfavourable for good working, especially so in the larger sizes of engines. As the power of the engine increased, the thickness of metal in the walls increased in proportion, and there was a greater quantity of heat retained, thus

(Mr. A. Rollason.)

increasing the temperature of the charge which on compression would give considerable trouble from premature ignition. To keep down the temperatures a reduced charge of gas had to be admitted, and if the gas was fairly constant in composition good results were obtained. Indicator cards, Trials C, tests 1, 4, 6, and 8, showed that with the same compression, by increasing the ratio of air to gas admitted, there was a corresponding lowering of the temperatures and mean pressure, the thermal efficiency remaining practically constant over a large ratio of air to gas. Another point brought out by the research was the value of poor qualities of gas for engine use. Trials D, tests 5, 6, 8, and 10, showed that with the same compression, and increasing the ratio of air to gas, by igniting the charge at early periods of the compression-stroke, good results were obtained.

On the point of economy, high-power engines would use fuel gases, the records showed that such gases could be satisfactorily used, but as the gases were low in heating value a greater volume would be required to be admitted per charge, and scavenging-out the products must be resorted to. By scavenging, a larger total volume of charge at a lower temperature could be drawn in, and as the power of the engine was in proportion to the combustible admitted, large engines should be arranged with a scavenging device. The cooler charge admitted to the cylinder had on ignition a slower rate of burning, which gave a lower initial pressure, owing to the variable specific heat of the gases and the greater volume, more heat or internal energy was given out on the expanding stroke, there was a higher mean pressure and thermal efficiency, with a corresponding less loss of heat in the exhaust, and no increase of heat to the water-jacket.

Mr. B. H. Thwaite noted that the reporter suggested, as a standard for thermal calculations, that as a result of employing as the gaseous fuel one of a character which involved, as an effect of the oxidation of part of its contents, a loss of heat due to latent absorption, that this thermal loss should be ignored. Such a proposal, if adopted, would destroy the effect of a true economic comparison between the employment of fixed carbon fuels, as an alternative to those containing hydrogen or hydrocarbons, or between the employment of a gaseous fuel containing only carbonic oxide as the combustible, as an alternative to that containing hydrogen or hydrocarbon. A true uniform standard should obviously permit the measurement of the loss of heat by latent influences to be exactly determined, and any calorimeter that failed to determine this loss is *pro tanto* imperfect and misleading. He was glad to notice that the reporter adopted the variable specific heat coefficients, but why did he prefer those of Mallard and Le Chatelier to the determinations of Vieille and his illustrious collaborator Berthelot? As far back as 1884, the writer drew attention to the limiting effects of the increase of the specific heat with temperature increase on the thermo-dynamic output of the combustion of fuel in a closed power-developing cylinder, and in 1885 he contributed an article to *The Engineer* * giving the result of the specific-heat investigations of the two last-named physicists and chemists. Although the reporter's test was full of interest, the results could hardly be considered representative of practice with large engines using gas of low calorific value.

The subjects of the phenomena of combustion in a gas-engine cylinder, and of the efficient transformation of gaseous fuel into power, were so complex that a thorough investigation would involve the exclusive time of a competent investigating staff for many months; nevertheless the reporter's investigations were gratefully acknowledged.

Mr. W. W. Tonkin wished to point out that the probability mentioned by the reporter (pages 1039 and 1054) of there being great variations in the temperature of the hot gases in a gas-engine cylinder had been frequently suggested. Many years ago the writer considered this question, and came to the conclusion that diagrams showing at successive intervals of time the variations of temperature of the gases cooling in a cylinder without expansion would be very similar in appearance to those representing the cooling

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* *The Engineer*, 2nd October and 13th November 1885.

(Mr. W. W. Tonkin.)

of a heated solid, Fig. 28.* In this diagram the various curves represented the temperature at successive intervals of time elapsed after cooling had begun on the outer surface, the vertical heights giving the temperatures. In the case of the solid the distance between the vertical ordinates represented both equal weights and volumes of the substance; but in the case of the cooling gas, they could only represent equal *weights* of the gases, the volume or actual space occupied by those in the cylinder varying with the temperature of each part at the moment. Professor Tyndall by experiments on radiant heat had proved that the absorbing power of a layer of gas depended on the number of molecules obstructing the ray of heat, irrespective of the space they occupied. The inclination of these lines might be said to represent the rate of loss of heat to the cylinder walls immediately after complete explosion and while the piston was nearly at rest, during which time probably the greatest loss of heat took place to the cylinder walls.

FIG. 28.

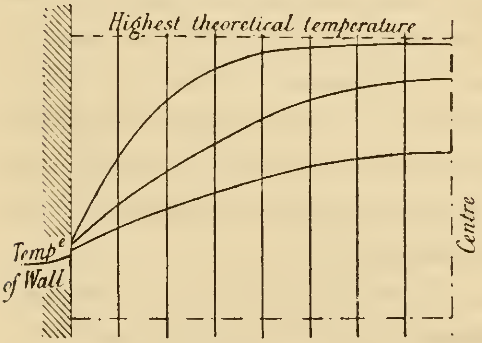
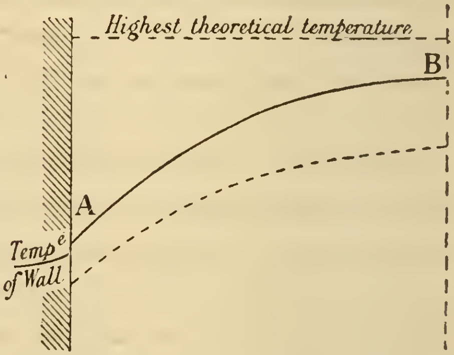


FIG. 29.



Let them now consider the effect on these lines when the gases also lost heat by expansion. Let the curve A B, Fig. 29, represent the curve of temperature in the cylinder at a given moment. If now a certain amount of expansion was allowed to take place *instantaneously*, the dotted line would represent the consequent fall of temperature in all parts of the cylinder, showing that the cooled outer portion might, by the sudden expansion, be reduced below the wall temperature; and this would require to be made up by transfer (without loss of pressure) from the hot interior before any more heat could pass out through the cylinder walls. In practice both modes of cooling occurred together, and it was possible to suppose a continuous expansion so rapid that the whole of the heat passing from the hot interior would be absorbed by the cold layer of gases lying against the cylinder walls, in merely preventing their temperature falling by expansion below that of the walls. In this case the *mean* cylinder temperature and pressure would follow a true adiabatic curve, and there would be no loss from wall-cooling during that rapid expansion. This argument applied to the surfaces of the piston and cylinder clearance, but owing to the continued movement of the piston the protecting layer of cooled gases at the sides was, as it were, being stretched out, bringing some of the hotter portions into closer cooling range of the cylinder walls, and thus counteracting to some extent the favourable effect of expansion, the amount depending on the relative proportions of the fixed and variable surfaces; but on the whole there was probably a considerable reduction in the cooling effect of the cylinder walls during rapid expansion.

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* Philosophical Magazine, April 1878. *Paper* by Professors Ayrton and Perry.

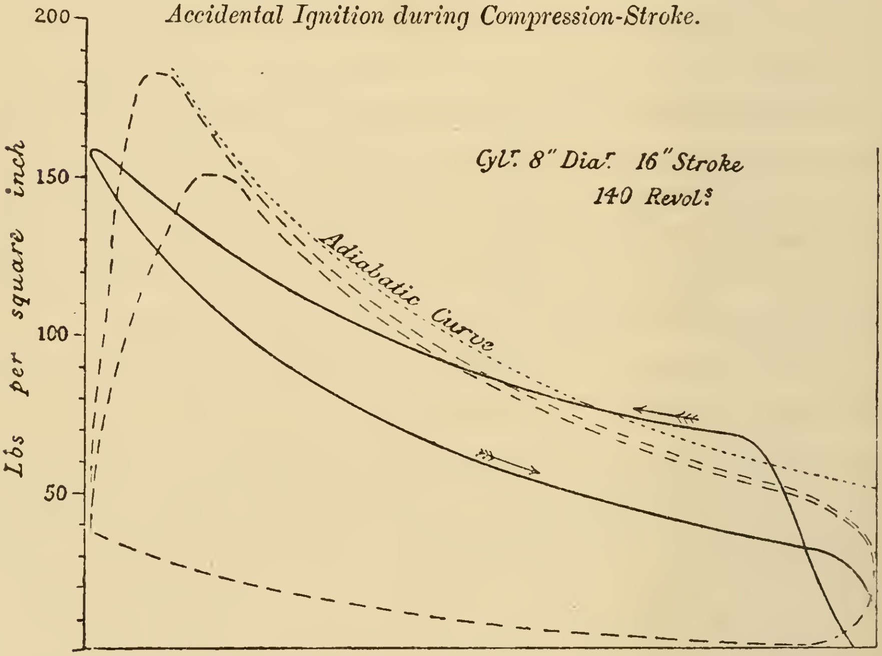
On the contrary an opposite effect was produced during compression, but as the temperature was usually low during compression it was not very noticeable. Some years ago however the writer obtained an indicator diagram, Fig. 30 (page 1148), from a Crossley electric light gas-engine, when the gas-mixture by some accident was ignited at the beginning of the compression stroke. In this case the explosion-curve rose above the ordinary expansion-curve (shown dotted) until complete inflamation had taken place; and then the curve of compression of the gas-products at a high temperature followed approximately an isothermal curve of equal temperature, cutting across the usual expansion-curve, while the following curve of re-expansion was almost a true adiabatic, thus showing a great difference in the cooling effects between the compression and expansion strokes.

The writer has tried thus to indicate some of the complicated actions taking place in a gas-engine cylinder, in addition to those due to dissociation, variable specific heat, etc.; and it would seem

(Mr. W. W. Tonkin.)

nearly impossible to follow and define properly those actions by experiments on gas-engines alone, however carefully made. The indicator diagram of the gas-engine was only the resultant of a number of forces acting simultaneously in the cylinder. Now it was an easy matter to resolve a number of known forces, varying in direction and amount, into one resultant; but it was impossible to reverse the process and deduce the separate forces acting from the one final resultant unless information of the more important forces could be obtained from other sources.

Fig. 30.—*Indicator Diagram from an Electric Light Engine. (Crossley.)*
Accidental Ignition during Compression-Stroke.



Seeing these difficulties with gas-engines, many experimenters have used closed cylinders (without pistons), in which the conditions were simplified and more easily controlled; but even in this case there would still be apparently three actions taking place simultaneously, namely dissociation, varying specific heat, and the cooling effect of the cylinder walls; and the true relative values of these were still comparatively unknown. The reporter (page 1039) had taken his values for the variable specific heat from experiments of Messrs. Mallard and Le Chatelier, which, so far as the writer could ascertain, were made by exploding gases in a closed cylinder; and the value of their deductions on the variable specific heat depended *entirely* on the correctness of their assumptions as to the small amount of dissociation present, and the cooling action of the cylinder walls. Other experimenters attributed the bulk of the loss to dissociation, or to cooling by the cylinder walls; all of them were therefore far from satisfactory. The writer would also point out that at present there did not appear to be any experimental data available of the specific heat of gases between about 250° C. and these explosion temperatures of 1,500° C. to 3,000° C. The intermediate values, if obtained, would afford a valuable check on the correctness of those deduced from explosion experiments. The writer would suggest that these intermediate values of the specific heat of gases could be more correctly obtained by means of a calorimeter slightly modified from one now used in ascertaining the heating power of gas. In this the gas was burnt at a certain rate inside the calorimeter, and the heat was absorbed by a current of water flowing through the apparatus. The rise of temperature of the water multiplied by the weight of water passing in the time of burning, say one cubic foot of the gas, gave the B.T.U. For ascertaining specific heats of the gases, this apparatus should be modified so that the gas could be burnt in a chamber or pipe outside the calorimeter; and arrangements should be made to vary as desired the temperature at which the products of combustion entered the cooling pipes of the calorimeter. Thermometers suitable for measuring high temperatures should be fitted to measure correctly the temperatures of the gases on entering and leaving the calorimeter. The air and gas should be delivered to the burner from measured gasholders in such constant proportion (say 10 to 1) that the burnt products would be of the same composition as the average gas-engine exhaust. Then when flow and temperatures were steady, the weight of cooling water passing (deflected into a separate vessel) during the time in which a certain volume and weight of the gas and air was passing, would, multiplied by the rise of temperature of the water, give the heat lost by that weight of gas-products in cooling between the temperature shown by the gas thermometers. The discharge

(Mr. W. W. Tonkin.)

temperature of the products should be above 100° C. to avoid the complication of condensed water. By varying the temperature of the gases as they entered the calorimeter, it would be possible to obtain a series of values of the specific heats between say 100° C. and 200°, 250°, 500°, 700°, 1,000°, to as high as it was possible to measure temperatures accurately; and these if plotted would show the gradual rise (if any) of the specific heat at constant pressure. If this curve showed a sudden increase at any part, it would indicate that dissociation had commenced at that temperature. If this was found to take place early in the series, it would be advisable to modify the apparatus, and to compress the united gas mixture (say 10 to 1) into a reservoir and supply it through a reducing valve and safety-gauzes to the burner, where it could be burnt under a pressure of 2, 3, or 4 atmospheres, the pressure being maintained throughout the cooling pipes by a valve at the end of the pipe. The rate at which the products passed would be measured after exit and expansion to atmospheric pressure in this case. The temperature of the gases entering the calorimeter would be varied as before, and a comparison of the varying-temperature series of trials under each of the various pressure conditions would give valuable and reliable information, both as to the specific heat and dissociation under the varying conditions, and up to temperatures more nearly approaching those found in gas-engines. Unfortunately the effects of both varying specific heat and dissociation were so similar; both of them caused a loss of apparent heat during the explosion, which appeared again during the subsequent cooling, that for any correct results it was necessary to have the power to vary the temperatures and pressures *independently* of each other, and to measure the temperatures by more certain means than the indirect method of calculating from the pressure produced.

When the continuous law of the true specific heat had thus been obtained independently, it could be employed with more confidence to determine the rates of cooling in closed vessels, preferably of a spherical form, and fitted with arrangements for igniting the gas in the centre. The effect of higher compression or greater density of charge on the cooling could be far better obtained in these closed spheres, simply by forcing in more mixture before ignition, as the surface remained exactly the same in each case, while in a gas-engine increased compression was only obtained by altering both size, proportion, and surface of the clearance space. If the results at different initial compressions were further checked by being repeated in a larger chamber, very correct information should be available of the actual rate of cooling per unit of surface.

In all these however they still had to deal probably with the effects of dissociation, of which the diagram of pressures gave no indication. The writer would suggest a modification of the experiments on explosion in spheres, by which he thought information could be obtained as to the presence and even the amount of dissociated gases in the cylinder at any moment after complete inflamation, and when the pressure was falling due to cooling. If at any determined moment a puff of pure air was introduced into the sphere (preferably in two opposite jets meeting and spreading in the hot centre) the result would be, if no dissociated gases were present, merely a slight rise in the pressure due to the additional air forced in ; the hot central core would divide its heat with the fresh cold air, but the mean temperature of the whole would not be affected by this mere exchange of heat. If however dissociated gases were present, the increased pressure and reduced temperature of the centre core would allow of recombination which would appear in an extra rise of pressure on the diagram above that due to the air admitted. The amount of air passed in could be ascertained subsequently by the fall of pressure in the reservoir from whence it came. It might be possible to pass in an excess of air to cause complete recombination, and thus ascertain the exact amount of dissociation present in the cylinder. The time of air admission could also be varied, thus giving reliable information as to the dissociation present at any part of the cooling diagram.

If correct data relating to the three points of (1) varying specific heat, (2) dissociation, and (3) cylinder wall cooling without expansion could thus be obtained independently with reasonable accuracy, it would be of very great assistance to the theory and

(Mr. W. W. Tonkin.)

practice of gas-engine design. It would also be of much assistance to gas-engine designers if the reporter would give particulars of the formula used by him in drawing the expansion curve on test B 2, Plates 177 and 184, of adiabatic expansion with varying specific heat, that is, the modifications required in the usual formula expressing the relations between temperature, volume and pressure during expansion.

$$\left(\frac{P}{P^1}\right) = \left(\frac{V^1}{V}\right)^{\gamma} \quad \frac{T}{T^1} = \left(\frac{V^1}{V}\right)^{\gamma - 1} \quad \frac{T}{T^1} = \left(\frac{P}{P^1}\right)^{\frac{\gamma - 1}{\gamma}}$$

Would he also state in which tests the junk ring on the piston was used or omitted?

The writer would also wish to correct the statement so often made that the chief cause of the improved efficiency of gas-engines was due to compression. It was rather the increased ratio of expansion, which in the Otto cycle increased with the compression, that gave a greater efficiency by turning more of the heat into work before exhaust. There should also be a saving by compression in the initial loss by cooling at explosion, due to the lessened surface of the clearance space at higher compression. The amount of this however depended largely on the good design and shape of clearance chamber. In the reporter's experimental engine, when using the junk ring for higher compressions the surface was actually increased on the junk ring, which was also thrust into the centre of the burning gases; and this extra initial loss from cooling during explosion no doubt considerably reduced the extra efficiency obtained from the higher ratios of expansion.

Professor Burstall wrote, in reply to Mr. J. Johnston (page 1136), that as regards the measurement of the temperatures, the difficulty of obtaining accurate values was not due to the apparatus, but was caused by the very fine wires breaking; no doubt a wire of 0·001 inch diameter would give a closer approximation to the actual temperature than a wire of 0·0015 inch diameter.

Cycles other than the Otto would be considered, if there was sufficient time, but at present it did not seem desirable to do so in view of the fact that the Otto was by far the most important. The ideal cycle proposed by Professor Meyer (page 1137) had been used by the reporter. The only objection to its general use as a standard of comparison was due to the fact, that in actual motors combustion took place partly during the forward motion of the piston; if from the point of maximum temperature an adiabatic curve be drawn, it might be above the adiabatic curve in the ideal engine, and for that reason the reporter did not advocate the cycle as a standard of comparison. He quite agreed with Herr Münzel's remarks (page 1140) as to the form of ignitor; the special form chosen was not that which would be used in an engine built for electric ignition, but was designed as the most convenient for the particular engine. Quite apart from the experiments quoted, the engine was frequently run for many hours at a time, and the ignition was always quite satisfactory. The reporter was quite in agreement as to the correctness of working at light load without cutting out charges, but would not be certain that the economy would be as good as with the hit-and-miss system. The values of the specific heat adopted were those which seemed to the reporter to be the most recent and complete.

Mr. Tonkin's communication (page 1145) raised many important points which influenced the explosion and expansion that took place in the cylinder; as regards the amount of dissociation that might take place, the best authorities were agreed that the amount of dissociation was directly proportional to the temperature and inversely proportional to the pressure, and therefore that in the cylinder of a gas-engine the amount of dissociation could be neglected.

The method proposed for the determination of the specific heat of gases was not one which lent itself to accuracy; the great difficulty in all determinations of specific heat, particularly at high temperatures, lay in the temperature measurements which were difficult to carry out as proposed. The explosion method would appear to be the more likely to be successful, if both pressure and temperature could be measured. The major portion of Mr. Tonkin's communication did not call for any reply, interesting as many of the points were. The complete elucidation of the gas-engine problem

(Professor Burstall.)

would only be obtained by experiment not only on engines, but to obtain knowledge on the behaviour and properties of gases at high temperatures. The reporter had purposely confined his attention to several special points, and was well aware that only the threshold of the subject had been touched upon.

The Institution of Mechanical Engineers.

PROCEEDINGS.

15th November 1901.

An Ordinary General Meeting was held at the Institution on Friday, 15th November 1901, at Eight o'clock p.m.; William H. Maw, Esq., President, in the chair.

The Minutes of the previous Meeting were read and confirmed.

The following Paper was read and discussed:—

"The Balancing of Locomotives;" by Professor W. E. Dalby, *Member*, of London.

Several working models of good and of defective balancing were exhibited, and the Figs. in the Paper were shown upon the lantern screen.

The Meeting terminated shortly before Ten o'clock. The attendance was 156 Members and 150 Visitors.

THE BALANCING OF LOCOMOTIVES.

By Professor W. E. DALBY, *Member*, of London.

Article 1.—*The object of this Paper* is primarily to explain and illustrate a convenient semi-graphical method of obtaining the magnitude and position of the balance weights for locomotives, and incidentally, to discuss and illustrate the different ways of dealing with the reciprocating masses in coupled engines, and to consider the effect of the balance weights on the permanent way and on the tractive effort of the engine.

The advantage of the method to be explained is its simplicity, and, in the case of engines in which the L and R cylinder gear are alike and symmetrically disposed, that it is self-checking.

The dynamical principle on which the method depends has been previously fully described by the author,* but for the sake of completeness a brief explanation of the fundamental ideas involved will be given here.

The Paper has been divided into nineteen separate Articles, as follows :—

1. Object of the Paper.
2. Principle of the Method.

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* "Balancing Engines," Institution of Naval Architects, 1899, page 185.

3. Definition of the Reference Plane.
4. Graphical Representation of the Centrifugal Force and Couple on the Reference Plane.
5. Conditions of Balance.
6. Preliminary Reductions.
7. Revolving and Reciprocating Masses.
8. Example 1: Inside Cylinder Single Engine, 26 inches stroke.
9. Example 2: Six-coupled Goods Engine, Lancashire and Yorkshire Railway.
10. Variation of Rail Pressure; Hammer Blow.
11. Example 3.
12. Speed at which a Wheel lifts.
13. Slipping.
14. Value of w; the Resultant Variation.
15. Example 4: Four-coupled Bogie Express Passenger Engine, Lancashire and Yorkshire Railway.
16. Distribution of the Reciprocating Mass between the Coupled Wheels.
17. American Practice.
18. Example 5: Eight-coupled Engine, Class E, Baldwin Co.
19. Four-cylinder Locomotives.

Art. 2.—*Principle of the Method.*—The first point to be clearly understood is, that the effect of a force F (Fig. 1), with reference to a point O, whose perpendicular distance from the line of action of F is a feet, is equal to—

(1) an equal and parallel force to F, indicated by f, acting at O;

(2) a couple, whose magnitude is Fa.

The application of this principle to the case of a revolving shaft, acted upon by the centrifugal force due to an attached non-axial mass, is the key to the method. Consider Fig. 2, in which a shaft OX carries a truly turned disc D, to which a mass M is attached. Let r be the distance of the mass centre of M from the axis of the shaft; then when the shaft turns at ω radians per second,

Fig. 1.

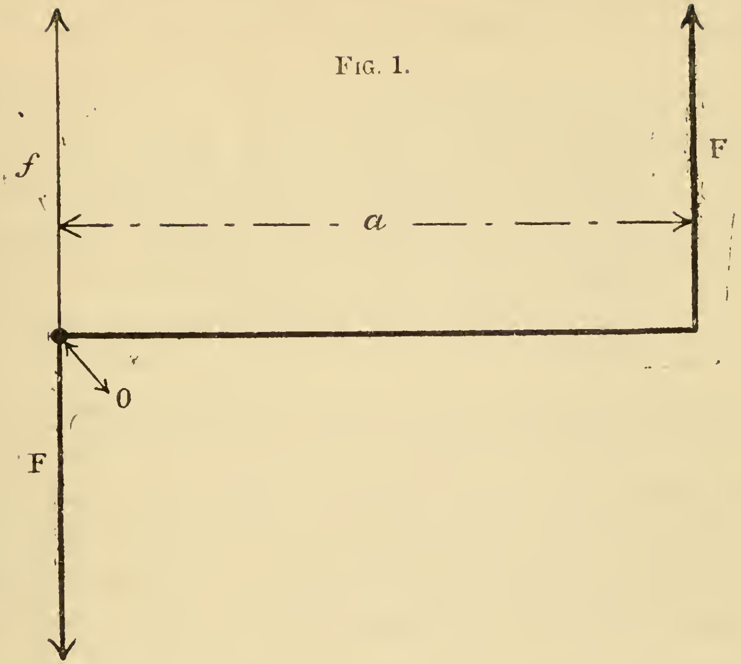
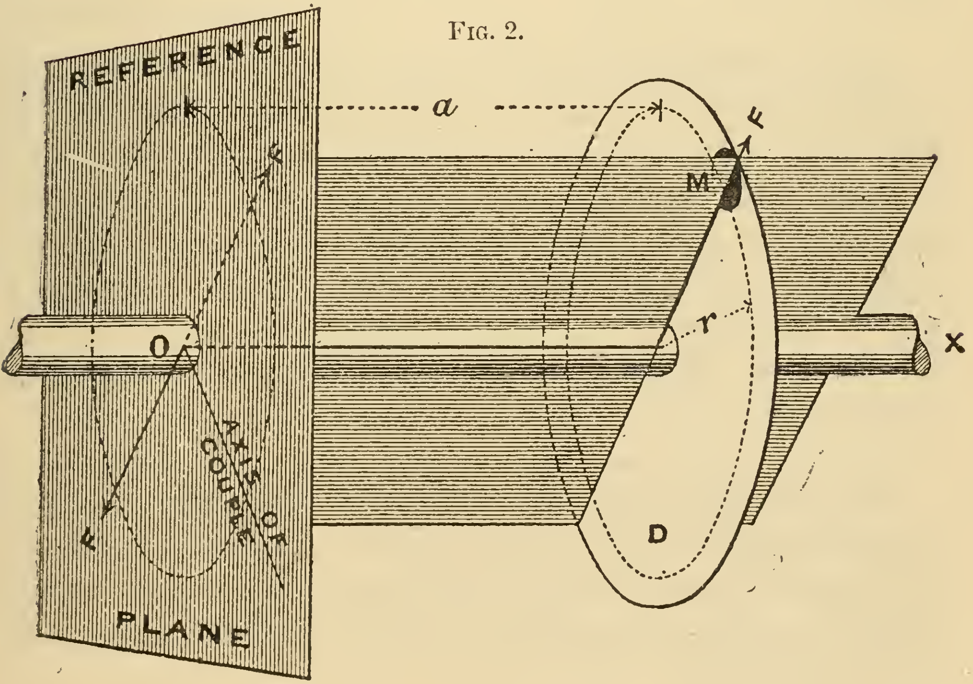


Fig. 2.



a centrifugal force, $M\omega^2 r = F$, acts upon the shaft. The effect of this force with reference to the point O, which may be taken anywhere, is—

(1) an equal and parallel force, $M\omega^2 r = F$, acting at O;

(2) a couple $M\omega^2 ra$ acting on the shaft tending to turn it about O, in the plane (shown shaded) containing the axis of revolution OX, and the radius of the mass M. A couple of this kind is usually called a "centrifugal couple" because the forces forming it are centrifugal forces.

In these expressions, and in all the expressions following, M or m is the mass measured in pounds, consequently the forces will be in absolute units, unless the expression be divided by g, in which case the forces are in lbs. weight, the usual unit of force. In balancing problems the *mass* of the different parts is under consideration, and the question of force is not immediately concerned, so that the forms $M\omega^2 r$, etc., are more convenient to use than $\frac{M\omega^2 r}{g}$. Hence M is always to be interpreted *mass measured in pounds* or tons as the case may be.

Art. 3.—*Reference Plane* (*Fig.* 2, *page* 1159).—A plane at right angles to the axis of revolution containing the point O is the plane in which the transferred force acts, and for convenience is called a reference plane. Both the reference plane and the plane in which the centrifugal couple acts rotate as though fixed to and forming part of the rotating system. The reference plane is best thought of as a drawing board keyed to the shaft at O, and therefore rotating with it. It is on this ideal drawing board that the balancing is worked out.

Art. 4.—*Graphical Representation of the Centrifugal Force and Couple on the Reference Plane.*—The transferred force acting at O may be represented by a line, OF in Fig. 2 (page 1159), drawn to scale in the reference plane. It must be drawn $M\omega^2 r$ units long, and parallel to the radius of M.

The couple may similarly (as shown in Fig. 2) be represented by its axis, but for the purpose in hand it is sufficient to represent it by a line drawn on the reference plane *parallel* to the *radius* of the mass, $M\omega^2ra$ units long.

The *direction* in which these lines are drawn must be carefully attended to. The line representing the force must always be drawn in a direction *from* the point O outwards. If the line representing the couple is drawn *from* the point O, outwards and parallel to the radius when the mass is to the right of the reference plane, it must be drawn radially *towards* O for a mass on the left of the plane, since the two masses tend to turn the system in opposite directions.

Art. 5.—*Conditions of Balance.*—If there are several masses attached to and revolving with the same shaft, the centrifugal force due to each is to be treated in the same manner, that is to say, a reference plane is to be chosen and each force separately referred to it, giving a system of forces acting at O, and a system of couples. The total unbalanced effect of the masses will be represented by—

(1) The resultant of the transferred forces acting at O;
(2) The resultant of the couples.

The conditions of balance for a system of revolving masses are evidently that, when the process of transference has been carried out with respect to any reference plane—

(1) There shall be no resultant force; *i.e.*, the force polygon in the reference plane must close.
(2) There shall be no resultant couple; *i.e.*, the couple polygon must close.

Art. 6.—*Preliminary Reductions.*—In drawing the lines representing the forces and couples they may be made proportional to Mr and Mar simply, because the ω^2, being the same for every mass in the system, and being common to any applied balance weights, may for the time being be considered equal to unity. At the end of the problem, if the actual magnitude of the resultant force, or resultant couple is required, the proper value of ω^2 must be associated with the line representing the resultant force or couple, found by measurement from the force or couple polygons.

It should be noticed that if the force and couple polygons for a given system respectively close, the system is in balance for all speeds. So far then as the speed is concerned, in finding the balance weights ω may always be written equal to unity. A further simplification is made in the work by first reducing all the masses to crank radius. Then the radius cancels out and the sides of the force polygon are drawn proportional to the respective masses at crank radius, and the sides of the couple polygon proportional to these masses respectively multiplied by their distances from the reference plane.

To find the actual force or couple in this latter case, the length of the line representing either of them must be multiplied by $\omega^2 r$, where r is the common radius to which all the masses are supposed reduced. By making the assumption that $\omega^2 r$ = unity—

(1) The mass at crank radius is the centrifugal force in absolute units.

(2) The mass at crank radius multiplied by its distance from the reference plane is the centrifugal couple in absolute units.

This assumption will be made throughout, so that, instead of mass and mass moment, the terms centrifugal force and centrifugal couple may be used.

Art. 7.—*Revolving and Reciprocating Masses.*—The moving masses in an engine may be divided into those which revolve with the crank shaft, and those which the crank shaft reciprocates. The preceding principles applying to revolving mass may be made to apply to the reciprocating masses. It is only necessary to suppose that the reciprocating masses are transferred to their respective crank-pins, and to treat them there as a separate revolving system, the balance weights found being those which when reciprocated will balance the reciprocating masses. This method of treatment really assumes an infinitely long connecting-rod, so that the solution obtained for ordinary rods is only approximate. The error involved is however negligible in locomotive work. Again in locomotive work it is almost the universal custom to balance the reciprocating masses by revolving masses placed in the wheels, the actual balance weight in a wheel being the resultant of the balance weights required for the revolving and reciprocating parts respectively. There is therefore no need to discriminate between the revolving and reciprocating parts in the process of finding the balance weights. Having settled how much of the reciprocating parts it is desirable to balance, include it with the revolving masses at the crank-pin, and consider the whole as a revolving system.

Models illustrating the above principles are shown on Plate 188, and described in the Appendix (page 1188).

The method adopted in the following examples is to take a set of reciprocating parts and to balance them considered as belonging respectively to an inside cylinder single engine, and a 6-coupled inside engine. The reciprocating parts, dimensions, and revolving parts where possible are those common to a large number of the Lancashire and Yorkshire 4-coupled and 6-coupled engines, the data of which have kindly been supplied by Mr. John A. F. Aspinall. Following a usual custom two-thirds of the reciprocating masses are balanced in each case.

Example 1.

Art. 8.—*Inside Cylinder Single Engine*, 26 *inches Stroke*—

Data.

Distance centre to centre of cylinders . .	1 foot 11 inches.
Distance between the planes containing the mass centres of the balance weights .	4 feet 11 inches.
Mass of unbalanced revolving parts per crank-pin reduced to 13 inches radius .	644 pounds.
Mass of reciprocating parts per cylinder at crank-pin radius	551 pounds.
Proportion of reciprocating parts to be balanced	two-thirds.

The mass to be balanced at each crank-pin is therefore 644 + $\frac{2}{3}$ of 551 lbs. = 1,011 pounds.

Draw the plan and elevation of the crank axle as shown in Figs. 3 and 4, so that in elevation the L driving-wheel shows to the front. Choose a reference plane to coincide with the plane

Fig. 3.

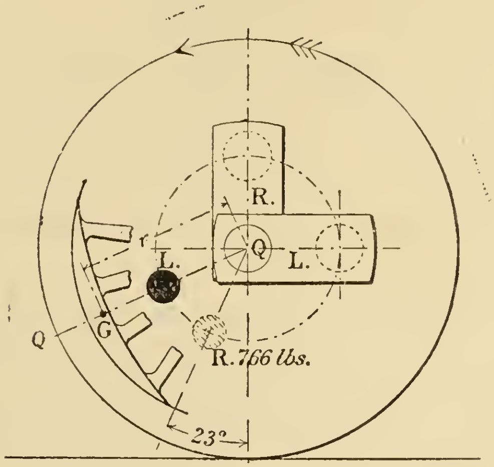
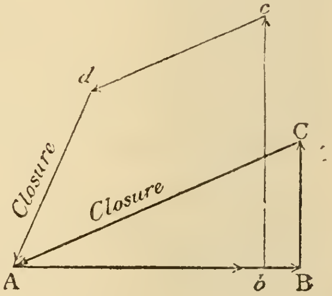


Fig. 5.



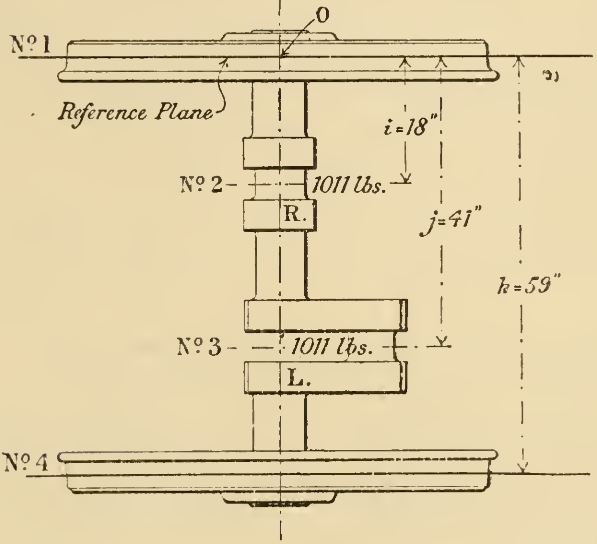


Fig. 4.

containing the mass centre of the R balance weight, and mark on the plan the three dimensions *i j k*. It will be found convenient to arrange the data in the way illustrated in the following Schedule No. 1. The numbers in italics are those which have to be found.

SCHEDULE No. 1.

Inside Cylinder Single Engine. Reference plane at No. 1, plane Fig. 4.

No. of Crank.	Distance from reference plane.	Equivalent mass at crank radius = centrifugal force when $\omega^2 r = 1$.	Equivalent mass moment = centrifugal couple when $\omega^2 r = 1$.
W.	X.	Y.	Z.
No. 1 R balance wt.	0	*766*	—
No. 2 R crank . .	18″	1,011	*18,198*
No. 3 L crank . .	41″	1,011	*41,451*
No. 4 L balance wt.	59″	*766*	*45,220*

Consider the R crank.—It is 18 inches from the reference plane. The centrifugal force, $\omega^2 r$ being unity, acting on the axle due to the 1,011 pounds at the R crank-pin is 1,011 absolute units, acting always along the crank radius outward from the centre. Transferred to the reference plane this is equivalent to an equal and parallel force acting at O, and a couple whose moment is represented by the product 1,011 × 18 = 18,198. The effect of the 1,011 pounds at the L crank-pin with respect to the reference plane is similar to a force at O represented by 1,011 and a couple represented by the product 1,011 × 41 = 41,451. To see what the resultant effect of these two couples is, and what mass must be added to balance them, choose any convenient scale and draw A B, Fig. 5 (page 1164), parallel to the L crank and 41,451 units long to any convenient scale, and B C parallel to the R crank 18,198 units long. A C represents the total turning effect, and therefore C A represents the moment of the couple which will effect balance. This line scales 45,220 units, and therefore the balancing mass must be of such magnitude, M, and placed at such distance, a, from the reference plane that

$$M a = 45{,}220\,;$$

and moreover M must be placed at crank radius in the relative angular position to the cranks given by C A (not A C). This line C A is called a closure, since it is the line which closes the couple polygon, giving at once the direction and magnitude of the balancing couple.

The *angular position* of the balance weight in the L wheel is therefore given by simply drawing a line Q Q, Fig. 3 (page 1164), parallel to C A. Its *magnitude* M, at crank radius, is found from the above product by dividing the 45,220 by 59 inches, the distance at which the balance weight is to revolve from the reference plane, giving 766 pounds. The three masses, namely 1,011 pounds, at the L and R crank-pins respectively, and 766 pounds in the L wheel, have now no tendency to turn the system about O at all. There is still left, however, the transferred equal and parallel forces due to these three masses acting at O. To find the resultant of these, choose a suitable scale, which will differ in general from the scale used to draw the couple polygon, and set out Fig. 5 (page 1164), A*bcd* respectively equal and parallel to these forces, *i.e.*,

A*b* parallel to the L crank 1,011 units long
bc „ „ „ R „ „ „ „
cd „ „ „ L balance weight radius C A, 766 units long

A*d* represents the resultant, and therefore *d*A, the force which will balance the system. This must be supplied by a mass revolving with the reference plane, that is in the right-hand wheel. The *angular position* of the R balance weight is given by drawing a line parallel to *d*A *from* the centre of the axle. The magnitude M is given by the length of *d*A. This measures 766 units. M is therefore 766 pounds.

The check on the accuracy of the work lies in the fact that, if the masses at the R and L crank-pins are equal, and that if their planes of revolution, and the planes in which the balance weights are placed are symmetrically disposed with regard to the central vertical plane of the engine, the two balance weights must be equal in magnitude, and their angular positions must be symmetrical with respect to the cranks. One balance weight is found from the couple triangle A B C, Fig. 5. The other is therefore known at once, and the drawing of the force polygon A*bcd* is therefore really unnecessary, though indispensable as a check, since dA should scale its already known magnitude, and should be inclined to the R crank at the same angle that C A is inclined to the L crank. A consideration of the above method will show that the artifice consists in choosing the reference plane to coincide with the plane of revolution of one of the unknown balance weights. Whatever be its mass, it has no moment with respect to O and can form no centrifugal couple acting on the system; balance amongst the couples due to the remaining three masses can then be effected, leaving the mass in reference plane to be adjusted to balance the forces transferred to O.

The method of finding the balance weights may be shortly summarised as follows:

(1) Draw a plan and elevation of the axle; mark on the necessary dimensions from the reference plane taken at the centre mass of the R balance weight.

(2) Fill in a Schedule like Schedule No. 1 (page 1165). Multiply the figures on the same level in columns X and Y together, placing the products in column Z.

(3) Set out the products in column Z as if to form a polygon; remembering the instructions of Article 4: the direction of each product is defined by the corresponding crank given in column W. The line necessary to close the polygon defines the angular position of the balancing product, *i.e.* of the balance weight. Transfer this direction to the elevation of the crank axle. Measure its length and divide it by the quantity k. The quotient is the magnitude of the balance weight at crank radius.

(4) Set out the quantities in column Y as if to form a polygon. The closing side taken in order with the rest defines the angular position and magnitude of the balance weight in the reference plane. For symmetrical engines this checks the work in the way already explained.

The actual mass, M_1 of the balance weight, depends of course upon the distance R of its mass centre G from the axis.

If r is the crank radius, M_1 is found from $M_1R = Mr = 766r$ for Example 1. Taking $r = 13$ inches, and $R = 36$ inches, which would be about the practicable distance for a 7-foot 3-inch wheel, $M_1 =$ 276 pounds. This should be arranged in crescent form between the spokes as shown in Fig. 3 (page 1164).

EXAMPLE 2.

ART. 9.—*Six-Coupled Goods Engine,* 18-*inch* × 26-*inch Cylinders. Lancashire and Yorkshire Railway.*—A drawing of the driving axle is shown in Figs. 6 and 7. There are in this case eight masses revolving in the eight planes shown in the plan, Fig. 7. The new

FIG. 6.

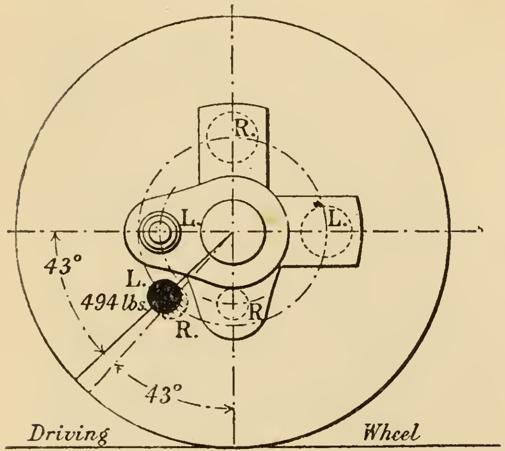


FIG. 8.

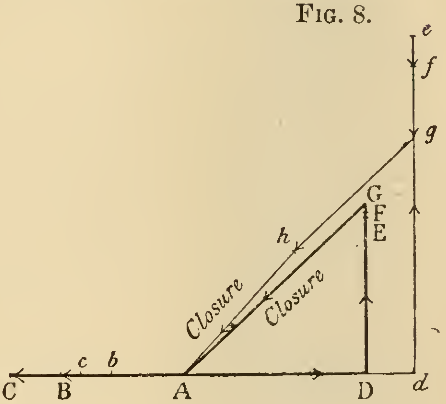
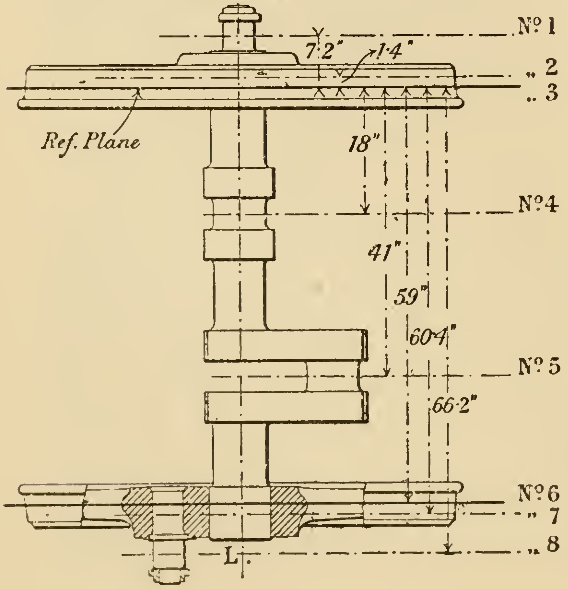


FIG. 7.



feature in this example is the coupling-rod. Each coupling-rod is to be divided between the three outside crank-pins in the proportion that they respectively support of its weight. In the present example the leading and trailing wheels each take 143 lbs. per crank-pin, the driving wheel 257 lbs. The total mass of each rod is 543 lbs. Since there is always a joint in the rod near the centre, the proportion may be arrived at expeditiously by placing the complete rod on three knife-edges at the three centre lines, each knife-edge being suitably supported in the platform of an independent weighing machine. The readings of the three scales give the proportions at the respective crank-pins.

In general the common radius of the outside cranks of a coupled engine is less than that of the inner cranks. The masses forming the system about the driving axle must be reduced to a common radius. Generally the radius of the inside cranks is used.

Driving Wheel.

For each outside driving crank-pin :—

Proportion of coupling-rod . . .	257 lbs.	at 10 inches.
Outside part of crank-pin and washer .	25 ,,	
Total	282 lbs.	

Equivalent to 217 lbs. at 13 inches radius.

The connecting-rod is the same as in the previous examples. The usual practice in England is to balance the proportion of the reciprocating masses decided upon entirely in the driving wheel This method is followed in the present case.

Collecting the data for the driving wheel:

DATA.

Distance centre to centre of cylinder .	1 foot 11 inches.
Distance ,, ,, ,, coupling-rods . . .	6 feet 1⅜ inches.
Distance between planes 2 and 7 containing mass centres of wheel cranks	5 feet 1¾ inches.
Distance between planes 3 and 6 containing mass centres of balance weights	4 feet 11 inches.
Unbalanced mass at each outside crank-pin in planes Nos. 1 and 8, reduced to 13 inches . . .	217 lbs.

Unbalanced mass of wheel cranks and part of pin in them reduced to 13 inches radius revolving in planes Nos. 2 and 6	96 lbs.
Unbalanced mass of revolving parts at each inside crank-pin	644 lbs.
Mass of reciprocating parts per cylinder	551 lbs.

Mass revolving at each inside crank journal in planes 4 and 5 is—

Revolving	644
Two-thirds reciprocating	367
Total	1,011

Fill in Schedule 2 for the driving-wheel and compute column Z.

Schedule 2.

6-Coupled Inside Cylinder Engine :—

DRIVING-WHEEL. Crank Radius = 13 inches.

Reference Plane at No. 3.

No. of Crank.	Distance from Reference Plane.	Equivalent mass at crank radius = centrifugal force where $\omega^2 r = 1$.	Equivalent mass moment = centrifugal couple where $\omega^2 r = 1$.
W.	X.	Y.	Z.
	inches.		
No. 1	− 7·2	217	− 1,562
No. 2	− 1·4	96	− 134
No. 3	0	494	0
No. 4	18	1,011	18,198
No. 5	41	1,011	41,451
No. 6	59	494	29,140
No. 7	60·4	96	5,798
No. 8	66·2	217	14,365

Draw the couple polygon, Fig. 8 (page 1168), AB, BC, CD, DE, EF, FG, to scale, taking the magnitudes from column Z. Notice that CD returns over AB and BC, and that EF, FG are drawn in a direction *from* their crank-pins *to* the axis, since the planes in which the corresponding masses revolve are on the opposite side of the reference plane to the other masses (see Art. 4). The closure GA measures 29,140, and it fixes the direction of the balance weight in plane 6, *i.e.*, in the L wheel. Dividing by 59, the quotient 494 is the magnitude of the balance weight. Check the work by drawing the force polygon, Fig. 8, A*b*, *bc*, *cd*, *de*, *ef*, *fg*, *gh*. The closure *h*A gives the direction of the R weight and it should scale 494 lbs., thereby checking the work. Remember that for the force polygon the direction of drawing is always *from* the axis parallel to the radius *towards* the crank-pin (see Art. 4).

Leading Wheel.—The unbalanced masses are wholly revolving, and should therefore be entirely balanced. They consist of the crank-arm, crank-pin, and a proportion of the coupling-rod. They revolve in different planes, forming a system of six masses revolving in six different planes which are tabulated in Schedule 3, Column X., relatively to the reference plane. An elevation of the leading wheel is shown in Fig. 9 (page 1173).

Additional data.

Mass due to coupling-rod . . .	143 lbs.
Mass due to part of pin and washer outside crank-arm	25 lbs.
	168 lbs. at 10 inches radius.
Mass of wheel crank and the part of the crank-pin in the wheel . . .	125 lbs. at 10 inches radius.

Fill these masses in Schedule 3 (page 1172).

SCHEDULE 3.

6-Coupled Inside Cylinder Engine.

LEADING WHEELS. Crank radius = 10 inches.

No. of Crank.	Distance from Reference Plane.	Equivalent mass at Crank radius = centrifugal force $\omega = 1$.	Equivalent mass moment = centrifugal couple when $\omega = 1$.
W.	X.	Y.	Z.
	inches.		
No. 1.	−7·2	168	−1,209
No. 2.	−1·4	125	−175
No. 3.	0	317	0
No. 4.	59	317	18,720
No. 5.	60·4	125	7,550
No. 6.	66·2	168	11,122

The couple and force polygons corresponding to the schedule are drawn in Fig. 10, and the balance weights they determine are shown, the L one black, and the R one dotted in Fig. 9.

The balancing of the trailing wheel is the same as for the leading wheel in every respect.

The radii at which the actual balance weights were put are:—

	ft.	in.
Driving wheel	1	10
Leading „	1	10
Trailing „	1	10

Therefore the masses of the actual weights are:—

$$\text{Driving wheel} = \frac{494 \times 13}{22} = 292 \text{ lbs.}$$

$$\text{Leading ,,} = \frac{317 \times 10}{22} = 138 \text{ lbs.}$$

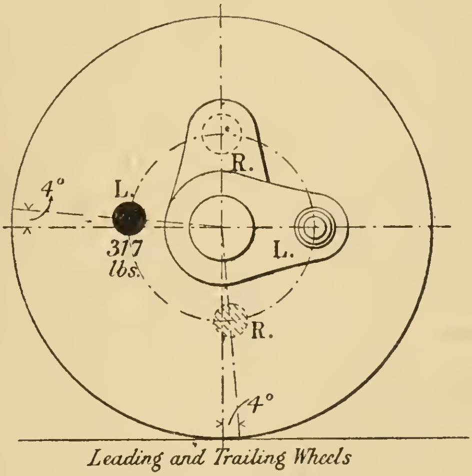
$$\text{Trailing ,,} = \text{,,} = \text{,,}$$

The angles, measured from the drawings of the polygons, which the L weights make with horizontal are:—

Driving wheel 43° below centre line.
Leading „ 4° „ „ „
Trailing „ 4° „ „ „

The left-hand side of the engine is shown in Fig. 17 (page 1183), the cranks being placed in their proper relation to one another, and the balance weights shown in black.

FIG. 9.



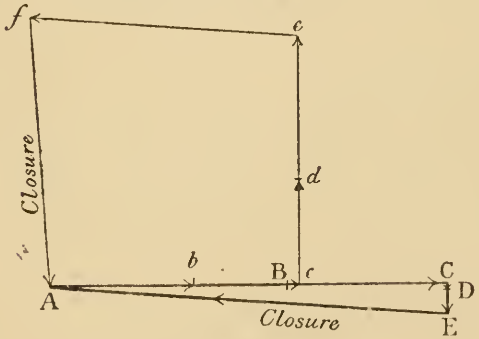


FIG. 10.

In this type of engine the distance between the planes containing the balance weights and those containing the wheel cranks is so nearly the same, that practically they may be treated as coincident. In the previous example the two planes have been retained in their exact positions for the sake of generality. The example then forms a type for coupled engines with double frames and overhung crank-arms.

A *four-coupled* inside cylinder engine is worked out in the same way as in the previous example.

ART. 10. *Variation of Rail Pressure. Hammer Blow.*—The variation of the pressure between the wheel and the rail, caused by the vertical component of the centrifugal force due to the part of the balance weight concerned in balancing the reciprocating masses, is called the "hammer blow." This description of the effect does not describe what takes place very well, because the variation of the pressure is not sudden, but continuous, except in the extreme case where the maximum value of the variation is greater than the weight on the wheel; in which case the wheel lifts for an instant, and coming down again gives the rail a true blow.

To estimate the variation of pressure on one rail in a given case, the balance weight concerned in balancing the reciprocating parts alone must be separated from the main balance weight. The quickest way to do this is to find the balance weight for the proportion of the reciprocating masses balanced, neglecting altogether revolving masses, which are presumably completely balanced and therefore affect neither the pull on the train nor the rail pressure. The schedule for the problem would be similar to Schedule 1, replacing the mass at each crank-pin by the proportion of the reciprocating mass to be balanced. A more convenient way is to consider that the crank-pin mass is unity. Then in the couple polygon of Fig. 5 (page 1164), AB would represent the dimension j, BC the dimension i. The closure therefore can be computed from,

$$\mathrm{CA} = \sqrt{i^2 + j^2} \quad . \quad . \quad . \quad . \quad (1)$$

and the magnitude of the balance weight for unity mass from—

$$\frac{\mathrm{CA}}{k} = \frac{1}{k}\sqrt{i^2 + j^2} \quad . \quad . \quad . \quad . \quad (2)$$

Then if M is the mass of the reciprocating parts per crank-pin, and q the fraction of this which is to be balanced, the magnitude of the balance weight m is given by—

$$m = \frac{q\mathrm{M}}{k}\sqrt{i^2 + j^2} \text{ pounds.} \quad . \quad . \quad (3)$$

Knowing the three dimensions, i, j, k; m may at once be calculated for any given value of q and M. The numerical value of the angle of direction is given by—

$$\tan \theta = \frac{i}{j} \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Let w be the variation of rail pressure in lbs. weight, *i.e.* the vertical component of the centrifugal force due to m.

α be the instantaneous value of the angle between the line or stroke and the radius of the balance weight m.

r the crank radius in feet.

ω the angular velocity of the wheel in radians per second.

Then

$$w = \frac{m \omega^2 r}{g} \sin \alpha \text{ lbs. weight} \quad . \quad . \quad (5)$$

If V represent the speed of the train in miles per hour, and D the diameter of the driving wheel in feet, containing the balance weight, $\omega = \frac{V5280 \times 2}{D3600}$. Substituting this in 4, and dividing by 2,240 to obtain w in tons (m is in pounds),

$$w = \frac{0 \cdot 00012 \, m r \mathrm{V}^2}{\mathrm{D}^2} \sin \alpha \quad . \quad . \quad . \quad (6)$$

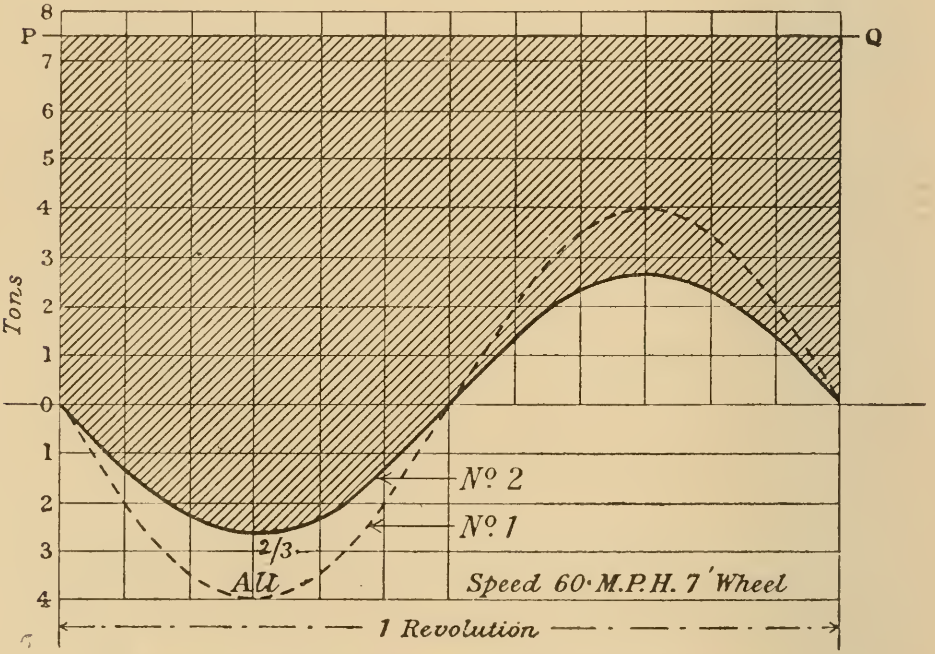
EXAMPLE 3.

ART. 11. Consider that Example 1 (page 1163) represents a 7-foot inside cylinder single engine. The value of equation 2 of the previous Article is 0·76. Therefore the magnitude of the balance weight required is 0·76 Mq pounds. If the whole of the reciprocating parts are balanced, $q = 1$ and M $= 551$ pounds, and therefore $m = 0 \cdot 76 \times 551 = 419$ pounds. The crank radius is 1·08 foot. Let V $= 60$ miles per hour. Then from equation 6 of the previous Article,

$$w = 4 \sin \alpha \text{ tons weight nearly.}$$

When the balance weight is at the top and bottom $\sin \alpha$ is a maximum $= +1$ and -1 respectively. The pressure on the rail is decreased in the first case by 4 tons, increased in the second case by 4 tons. Supposing the load on the axle to be 15 tons, *i.e.*, 7½ tons per wheel, at every revolution the pressure is alternately decreased and increased by about 54 per cent. If two-thirds of M be balanced, the percentage variation is reduced to two-thirds of this, or 36 per cent. Fig. 11 shows the variation of rail pressure for one revolution of the driving-wheel (Curve *No. 1*), on the assumption that the whole of the reciprocating parts are balanced, *No. 2*, two-thirds of them. Line P Q represents $7\frac{1}{2}$ tons, the static load on the wheel. The width of the shaded figure therefore represents the rail pressure, when the speed is 60 miles per hour, giving adhesion,

Fig. 11.



Weight of reciprocating parts 551 lbs. Stroke 1·08 foot.

supposing two-thirds of the reciprocating parts to be balanced. The variation of rail pressure due to the obliquity of the connecting-rod is relatively negligible.

Art. 12. *Speed at which a Wheel lifts.*—When small wheels are used, as in coupled goods engines, the piston speed increases for a given speed of travelling, and the rail pressure variation must be carefully considered in the balancing, or the wheels may leave the rail altogether at every revolution, a mistake in design not entirely unknown in practice. The formula (Eq. 6, Art. 10, page 1175) may easily be adjusted to find the speed at which this takes place for a given case. Let W be the weight on the wheel; then the pressure at the rail is given at any instant by $W - w$.

If $w = W$ this becomes 0 for the top position of the weight and 2 W for the bottom position. Hence putting W for ω in equation 6, sine a being 1, and solving for V—

$$V_o = \sqrt{\frac{D^2W}{0 \cdot 00012\, mr}} \quad . \quad . \quad . \quad . \quad (7)$$

V_0 being the speed in miles per hour at which the rail pressure becomes instantaneously nothing every time the balance weight passes through its highest position. Take the data of example 3, where $W = 7 \cdot 5$ tons and $m = 419$ lbs.; for full balance, $V_o = 82$ miles per hour approximately. If two-thirds of the reciprocating masses are balanced, $m = 280$ lbs. approximately and $V_o = 100$ miles per hour approximately. These two calculations show that two-thirds is about the greatest proportion of the reciprocating mass which should be balanced in a single engine. The engine may not slip because the other wheel may provide sufficient adhesion at the instant. To detect if slipping is about to take place the turning effort on the crank axle must be compared with the couple resisting slipping; this latter couple depends upon the sum of the rail pressures.

Art. 13. *Slipping.*—The driving wheels tend to slip when the turning effort on the crank axle is equal to the couple resisting slipping. The forces of this latter couple are the frictional resistance at the rail, and the equal parallel, and opposite tractive force, at the driving horns; the arm of the couple is the radius of the driving wheel. The forces of this couple vary directly as the pressure between the wheel and the rail. If W_1 is the load on the two wheels, w_1 the resultant variation of rail pressure, the greatest value of the frictional resistance is about $\frac{W_1 - w_1}{5}$. Therefore if the turning effort on the crank-shaft is greater than the couple—

$$\left(\frac{W_1 - w_1}{5}\right) R \quad . \quad . \quad . \quad (1)$$

R being the radius of the driving wheel, slipping will occur.

Art. 14. *Value of w_1 the Resultant Variation.*—The resultant of the two balancing masses is equal to a single mass placed on the prolongation of the line bisecting the angle between the two cranks, Fig. 16 (page 1181), and equal in magnitude to the square root of twice the square of the part of the reciprocating masses balanced. If M is the mass of the reciprocating parts per cylinder, and the fraction q of this is balanced, the magnitude of the mass which is the resultant of the R and L balancing masses for the reciprocating parts is—

$$1 \cdot 41 \ \mathrm{M}q \text{ pounds} \quad . \quad . \quad . \quad (2)$$

acting at 135° with the direction both of the L and R cranks. The maximum value of the force due to this is—

$$w_1 = \frac{1 \cdot 41 \ \mathrm{M}q \times \omega^2 r}{g} \text{ lbs. weight} = 0 \cdot 00077 \ q\mathrm{M}n^2 r \text{ tons weight} \quad (3)$$

where n is the revolutions per second, g being introduced to give the force in lbs. weight or tons weight as the case may be. The value in terms of the angle α, α being the angle between the line of stroke and the radius of the resultant mass, is $w_1 \sin \alpha$. This will be $+$ or $-$ according to the sign of sine α. The couple resisting slipping is therefore—

$$\mathrm{R}\left\{\frac{\mathrm{W}_1 - 0 \cdot 00077 \ \mathrm{M}n^2 r \sin \alpha}{5}\right\} \quad . \quad . \quad . \quad (4)$$

in terms of the variable angle α. The maximum value of this expression occurs when $\alpha = 270°$ and the minimum when $\alpha = 90°$. It is understood that the angle α is measured counterclockwise, starting from an initial line to the right.

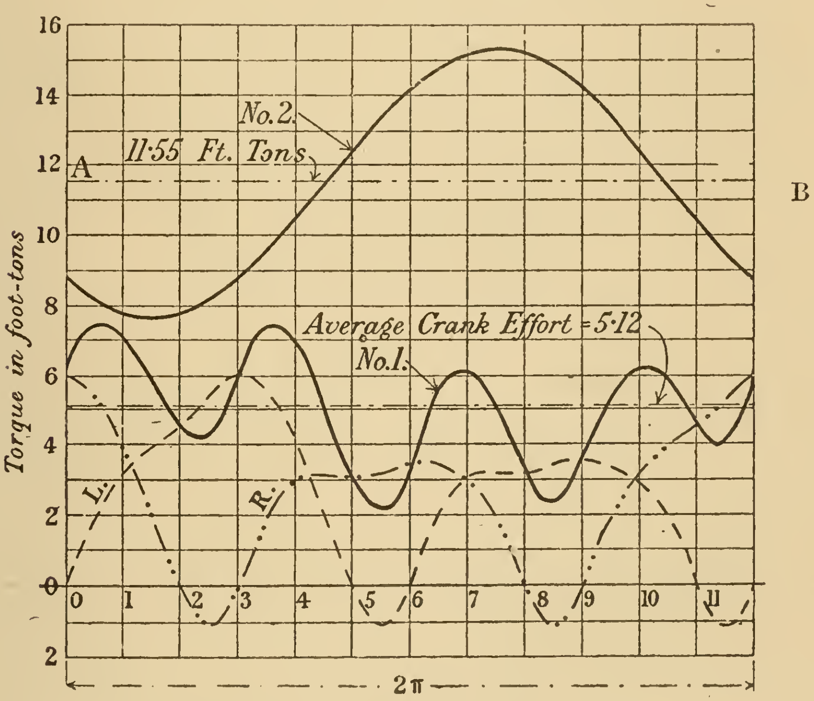
Example 4.

Art. 15. To further illustrate this point, the actual driving effort is compared with the couple resisting slipping for a complete revolution, Fig. 12 (page 1179), in the case of a Lancashire and Yorkshire four-coupled bogie express passenger engine, running at 65 miles per hour, two-thirds of the reciprocating parts being balanced. Cylinders 18 inches × 26 inches. Wheels 7 feet diameter. The ordinates of curve *No. 1*, Fig. 12, show the value of the driving effort, or torque on the driving axle; those of curve

No. 2 the couple resisting slipping. It will be noticed how nearly the two values approach for crank position 1. If this had been a single engine, and with a little more steam, curve *No. 1* would have cut *No. 2*, slipping being the inevitable result. In the case in question, the coupled wheels would come into play and prevent it.

7 feet, Four-Coupled Bogie Express Passenger Engine, L. and Y. Ry.
Cyls. 18″ × 26″. *Recip. Masses* 551 *lbs. per Cyl.*

FIG. 12.
Driving Effort and Couple resisting Slipping.



The method of drawing the curves is as follows:—

(*a*) Find the nett driving pressure on the piston from the indicator cards, by taking the intercepts between the steam line of one diagram and the exhaust line of its fellow. The shaded parts of the diagram, Fig. 13 (page 1180) show the width to be taken for the left end. These are plotted in Fig. 14 (page 1180), curve *No. 1* for both ends. The diagram is calibrated to give the total pressure acting on the piston. (Piston 18 inches diameter.) The numbers on the horizontal axis are those corresponding to the numbers on the crank circle, Fig. 16.

(b) These pressures are modified by the forces required to accelerate the motion of the piston. These are quickly found by using Klein's construction. The curve representing

7 feet. Four-Coupled Bogie Express Passenger Engine. L. and Y. Ry.
Cyls. 18" × 26". Recip. Masses 351 lbs. per Cyl.

Fig. 13.

Total I.H.P. = 548. Boiler Pressure 160 lbs. Cut-off 20%.
Speed 65 miles per hour. Revs. 251 per minute.
Spring 200. I.H.P. 274.

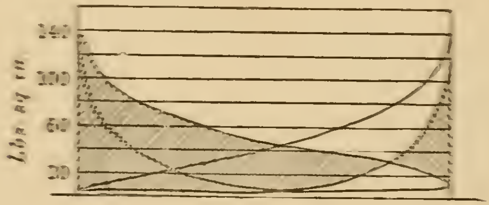
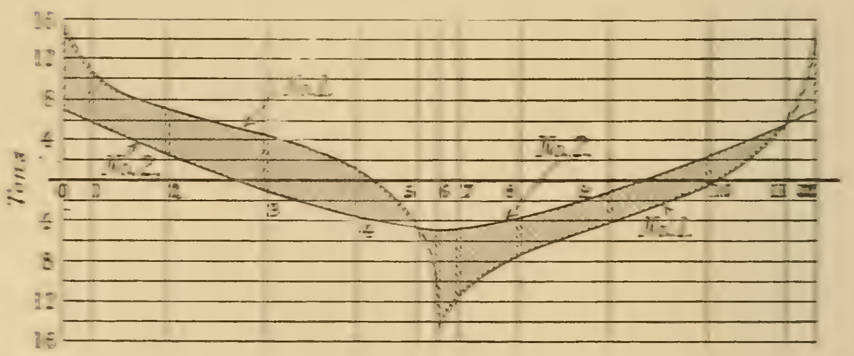


Fig. 14.

Total Pressure on Piston (plotted from Fig. 13).
Curve No. 1.—Total Pressure on Piston (plotted from Fig. 13).
„ No. 2.—Forces required to accelerate motion of Piston.



them. No. 2, Fig. 14, is plotted to the same scale as the nett driving pressure on the piston. The effect is to decrease the pressure acting to turn the crank during the first part of the stroke, and to increase it during the second part. The width of the shaded figures therefore gives the value of the force operating to turn the crank for any given crank angle. These have been re-plotted in Fig. 15. Notice how much more uniform this force is made by the effect of acceleration.

(*c*) The crank effort diagram is constructed in the usual way. The curve marked L in Fig. 12 (page 1179), is the crank effort curve corresponding to the pressures of Fig. 15. The curve corresponding to the R crank is assumed to be the same. It is drawn in for a phase difference of 90°. The two are then added to get curve *No. 1*, Fig. 12 (page 1179), giving the total turning effort on the crank in terms of the crank angle.

Fig. 15.

Resultant Crank-Effort (re-plotted from Fig. 14).

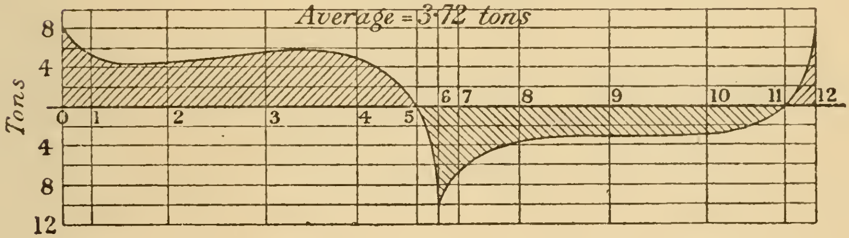
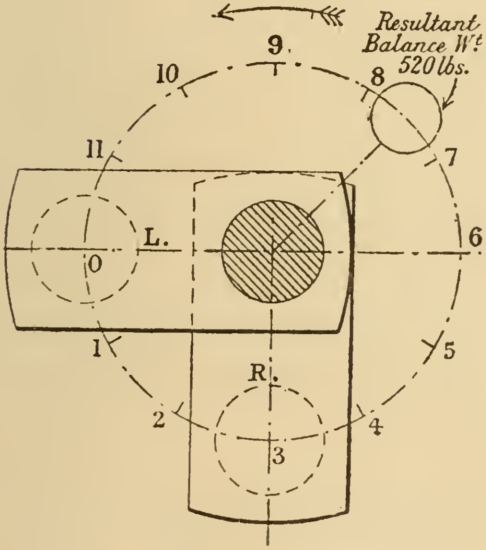


Fig. 16. *Crank Circle.*



Crank Radius 1·08 *ft.*
Rod 6·166 *ft.*
Revs. 251 *per min.*
Speed 65 *miles per hr.*
Radial acceleration of Crank pin 750.
Wheel 7 *ft. diam.*

(*d*) The weight on the driving wheels is 16½ tons; and they are 7 feet in diameter. The resisting couple due to this, assuming one-fifth available for adhesions is $\frac{16\cdot 5}{5} \times 3\cdot 5 =$ 11·55 foot-tons. The mass of the reciprocating parts per cylinder is 551 pounds, two-thirds of which is balanced. Referring to Art. 14, Eq. 2, $M = 551$ $q = \frac{2}{3}$. Therefore the magnitude of the resultant mass is 520 pounds, acting as shown in Fig. 16. At the time the diagrams were taken the crank axle was making 251 revolutions per minute $= 4\cdot 2$ revolutions per second, and $r = 1\cdot 08$ feet. Therefore $\omega^2 r = 4\ \pi^2 n^2 r = 750$. The maximum value of the force due to this, found from Eq. 3, Art. 14, expressed in tons is 5·4. The wheels are 7 feet diameter. The value of the corresponding resisting couple, allowing one-fifth for adhesion is $\frac{5\cdot 4 \times 3\cdot 5}{5} = 3\cdot 78$ foot-tons. The expression for the value of the resisting couple in terms of the angle a is then $11\cdot 55 - 3\cdot 78 \sin a$ (this is the value of Eq. 4, Art. 14; the + sign is used here however because the angle is measured counterclockwise, but *downwards* from an initial line to the left, see Fig. 16), the sign of the second term being determined by the sign of its trigonometrical factor. To plot this quickly, draw the line A B, Fig. 12 (page 1179), to represent the resisting couple due to the weight on the wheels alone, that is, 11·55 foot-tons, and on it as base construct a sine curve whose maximum ordinate is 3·78, allowing for the phase difference between the radius of this resultant mass and the cranks.

ART. 16. *Distribution of the Reciprocating Mass between the Coupled Wheels.*—A way of decreasing the variation of rail pressure in coupled engines is to divide the balance weight used to balance the reciprocating parts between the coupled wheels. The effects of these separate weights on the engine frame add up to the same horizontal effect as that due to the single balance weight, m, in the driving wheel. The variation of rail pressure is reduced at the driving wheel, a proportional variation, however, being introduced at the coupled wheels to which part of the balance weight is transferred. There is also a redistribution of pressure at the horns.

To illustrate this, consider Example 2 (page 1168) again. Fig. 17 shows the crank circles drawn out with the balancing masses, shown in

Fig. 17.—*All revolving mass and two-thirds reciprocating mass in Driving Wheel.*

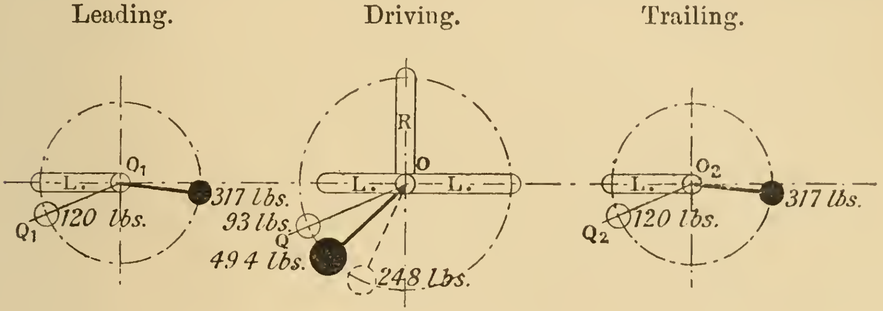


Fig. 18.—*All revolving mass and two-thirds reciprocating mass equally distributed.*

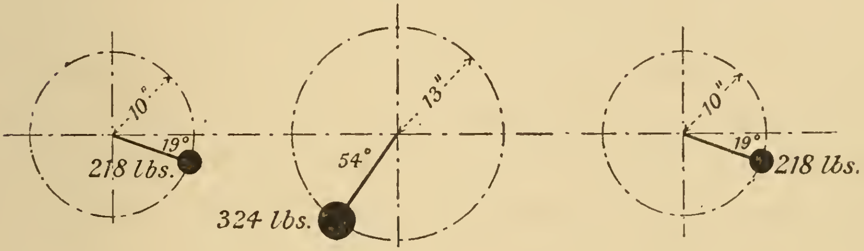
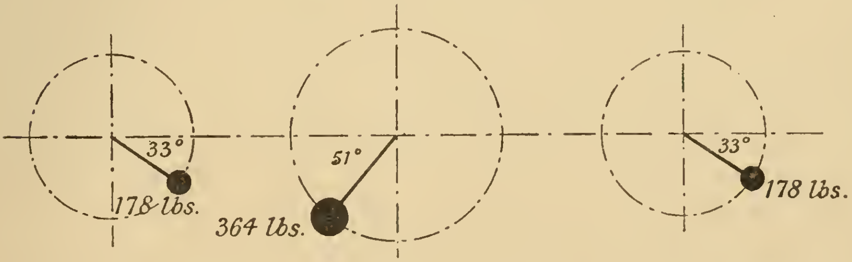


Fig. 19.—*All revolving mass and all reciprocating mass equally distributed.*



black, already found for the complete balance of the revolving parts and two-thirds of the reciprocating parts. To find what part of the driving-wheel balance-weight balances the two-thirds of the reciprocating parts, use formulae 2 and 3, Art. 10 (page 1174). The value of equation

2 is 0·76 for the example in question. The mass of the reciprocating parts is 551 pounds. The value of m for $q = \frac{2}{3}$ is therefore $\frac{0 \cdot 76 \times 551 \times 2}{3} = 279$ pounds placed in the L wheel at an angle such that $\tan \theta = \frac{18}{41}$. Therefore $\theta = (23° + 180°)$ measured from the L crank direction. This angular position is shown by the line O Q in the driving wheel, Fig. 17 (page 1183). The part required for the revolving parts on the driving axle is 248 pounds placed as shown by the dotted circle. Draw lines $O_1 Q_1$, $O_2 Q_2$, in the leading and trailing wheels respectively, parallel to the radius O Q in the driving wheel, and place one-third of the 279 pounds, *i.e.* 93 pounds, at each wheel, remembering that it is at 13 inches radius. Reduced to 10 inches radius, the radius of the balance weights being already found for the revolving parts in the leading and trailing wheels, it becomes 120 pounds. Considering the leading wheel, the 120 pounds due to the transferred mass combines with the 317 pounds already found, to form a resultant balance-weight of 218 pounds at 10 inches radius, placed as shown in Fig. 18. Considering the driving wheel, the 248 pounds required for the balance of the revolving parts combine with the 93 pounds left for the reciprocating parts to form a resultant balance-weight of 324 pounds placed as shown in Fig. 18. The trailing wheel masses combine similarly to the leading wheel masses. Thus Fig. 18 (page 1183) shows the balance weights, assuming two-thirds of the reciprocating parts to be balanced by masses equally distributed between the coupled wheels. Similarly Fig. 19 shows the balance weights, supposing the whole of the reciprocating parts to be balanced. In this case $m = 419$ lbs., the part in each wheel to be combined with the revolving weight is 140 lbs. at 13 inches radius = 182 lbs. at 10 inches radius. These weights balance the whole of the reciprocating masses, and at the same time the maximum variation in the rail pressure is reduced from 7·8 tons to 2·6 tons. This is unquestionably the best way to deal with whatever proportion of the reciprocating masses is balanced, so far as the permanent way is concerned; and with regard to the variation of tractive effort, the whole of the reciprocating masses may be balanced without introducing too great a variation of rail pressure.

In the case of a six-coupled engine, in which there is no separate small leading wheel or bogie, the division might be made in a different proportion, giving three-eighths each to the driving and trailing wheels, and the remaining quarter to the leading wheel if the leading wheel were lightly loaded.

If this method of distributing the reciprocating masses is adopted, it is only necessary to include in the Schedule of the leading wheel the one-third of the reciprocating mass assigned to them, acting at two imaginary cranks, parallel, and the same distance from the reference plane as the crank from which the mass has been transferred. For example, Schedule 4 would contain two more planes 18 inches and 43 inches from the reference plane, the corresponding masses being 140 lbs., the masses 1,011 in Schedule 1 being each replaced by the revolving mass plus one-third the reciprocating, *i.e.*, 644 + 140 = 784 lbs.

Art. 17. *American Practice.*—Mr. Henszey, of the Baldwin Locomotive Works, has kindly furnished the following details of their practice:—

All the revolving parts and two-thirds of the reciprocating parts are balanced on single expansion engines of the ordinary type. All the revolving parts and three-quarters of the reciprocating parts are balanced on the Vauclain compounds. The weights balancing the reciprocating parts are distributed equally between the coupled wheels. One-third of the connecting-rod is included with the reciprocating masses, and the remainder with revolving parts. The coupling mass of the rod is distributed between the crank-pins in the proportion which they respectively support of its weight. The parts are balanced as though their respective mass centres revolved in the same plane.

Example 5.

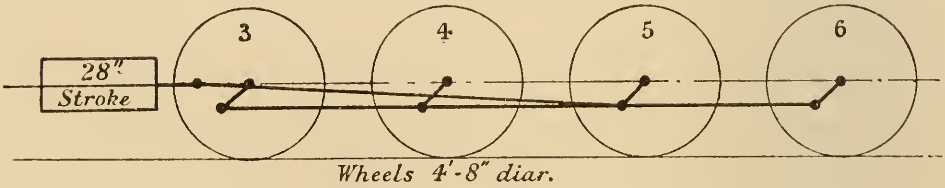
Art. 18. 8-*Coupled Engine, Class E, Baldwin Company.*—Fig. 20 (page 1186) shows the arrangement of the wheels.

The mass of the reciprocating parts, including one-third of the connecting-rod, is 1,170 lbs. Of this two-thirds is balanced, which, distributed equally between the coupled wheels, gives 195 lbs. per wheel.

The mass to be balanced in each wheel is made up as follows:—

	Wheel numbers.				
	No. 3.	No. 4.	No. 5.	No. 6.	
Reciprocating parts equally distributed . . .	195	195	195	195	pounds
Revolving parts—					
Two-thirds connecting-rod	—	—	464	—	,,
Coupling-rod . . .	169	214	265	106	,,
Wrist pin . . .	73	90	275	86	,,
Crank-hubs . . .	184	204	272	204	,,
At 14 inches radius .	621	703	1471	591	,,
At 16¼ inches, the radius of the mass centres of the balance - weights thus become . . .	531	605	1267	508	,,

FIG. 20.



ART. 19.—*Four-Cylinder Locomotives.*—The reciprocating masses in 4-cylinder locomotives may be arranged to balance amongst themselves without using balance weights at all. Under these circumstances, assuming the revolving masses to be balanced, there will be no variation either in rail pressure or tractive force, and no swaying couple. The engine will in fact be perfectly balanced, neglecting the errors which arise from the obliquity of the connecting-rod and the valve gear. The crank angles involved in balancing four reciprocating masses amongst themselves in general involve the employment of a separate set of valve gear per cylinder. Considerable mechanical simplicity may be obtained by arranging the cranks in two pairs, the two cranks in each pair being at 180° with each other, the pairs themselves being at 90°. With this

arrangement, assuming that each of the four sets of reciprocating masses are equal in magnitude, there will be no variation of tractive force exerted by the engine and no variation of rail pressure; there will be left however a swaying couple, which will in general necessitate the addition of balance-weights to minimise its effect at high speeds. The revolving weights added to do this introduce a variation of rail pressure, but do not affect the tractive force.

If four sets of valve gear are employed, the crank angles may be arranged for balance in a variety of ways, though complete balance cannot be effected by any arrangement of four cranks mutually at right angles. If a set of crank angles and masses for complete balance amongst the reciprocating masses are found, and decided upon, then, if the revolving masses are made in the same proportion amongst themselves that the reciprocating masses are, no balance-weights will be required for the revolving masses at the crank axle. That is, if the reciprocating masses are in the proportion,

$$a : b :: c : d,$$

the revolving masses must be in the same proportion, if they are to be in balance amongst themselves without the addition of balance-weights. Thus it is possible to construct a locomotive in complete balance (neglecting the obliquity of the connecting rod) without the addition of balance-weights of any kind, by properly proportioning the masses and crank angles, but whether such an engine would be satisfactory in all of the many other exacting conditions it has to fulfil is a matter which can only be decided by experiment.

In conclusion, the author wishes to thank Mr. Aspinall for the practical data he has placed at his disposal, and also Mr. Henszey for particulars of the practice of the Baldwin Company.

The Paper is illustrated by Plate 188 and 20 Figs. in the letterpress.

APPENDIX.

Description of Models.

The model, Fig. 22, Plate 188, specially illustrating the balancing of locomotives, is made to scale, so far as the crank-axle centre lines and the connecting-rod centres are concerned, from one of Mr. T. W. Worsdell's four-coupled passenger engines. Placed on rollers, the jigging effect on the train may be studied. Placed on rollers and partially suspended, so that the weight on the trailing roller is small, as shown in the second model, Fig. 22, the hammer-blow may be brought out and experimentally demonstrated. Hung in chains, the unbalanced couple producing lateral oscillations is made evident. Thus the various points connected with the balancing of locomotives may be illustrated and studied. The four-crank model is proportioned to represent more suitably a marine engine, the ratio of the length of the connecting-rod to the crank being small. It may however be taken just as well to represent a four-cylinder locomotive. In this model the crank angles and the reciprocating masses are adjustable, and many interesting problems may be illustrated, including those of secondary balancing—that is, the adjustment of the parts to eliminate the effect of the obliquity of the connecting-rod. When this model is suspended from springs, as shown in Fig. 21, and driven by means of the motors there shown, any want of balance is indicated by the oscillations produced. The effect of synchronism may be shown by adjusting the speed, so that the number of revolutions per second of the engine is equal to the number of vibrations per second which the model makes, when displaced from its position of equilibrium and allowed to oscillate vertically.

Discussion.

The President said that when Professor Dalby commenced his lecture he hinted that the subject he was going to deal with was an old one, but he thought Professor Dalby had shown that, if it was an old subject, there was a great deal of very interesting new information to be given about it, and he was sure the members would be all very grateful to the Professor for the very clear way he had put forward the facts. The members had already expressed their feeling by applauding Professor Dalby, but he asked them again to signify their very hearty thanks for the lecture he had just delivered.

The President hoped that in the discussion some help would be given by locomotive engineers, in furnishing information as to the practical effects of distributing the amount of balancing required for the reciprocating parts of the locomotive. He much regretted that Mr. T. Hurry Riches, who had attended the Council Meeting that afternoon, and who had made some experiments on the subject, had been called away to Cardiff, and was not able to be present. But he had promised to send a written communication, which the members would all be pleased to read. Mr. Aspinall and Mr. Ivatt were also, he regretted to say, unable to be present, but he had no doubt there were many locomotive men in the room who could give their experiences.

There was one point in connection with the distribution of the balance-weights required to counteract the effect of the reciprocating parts between the different pairs of wheels of that portion which Professor Dalby did not mention, although no doubt he had it in his mind, namely the effect of distributing the weights upon the wear and tear of the coupling-rod bearings. Taking an extreme case, and supposing that the amount of balance-weight put into the driving wheels in order to balance the reciprocating parts was such that at a given speed slipping must take place, it followed that in a coupled engine the whole thrust of the pistons would be communicated through the coupling-rods to the other wheels, that was, the coupling-rods would be doing the whole work of utilising the adhesion weight of the engine. Mr. Hurry Riches in some of his engines had

(The President.)

distributed what might be called the balancing of the reciprocating parts equally between the two pairs of coupled wheels, and he had found not only an advantage in other respects, but great advantage in reducing the wear and tear of the coupling-rod bearings. He trusted there were some other locomotive engineers in the room who would give the results of their experience in this direction. The practice of distributing that part of the balance-weights required for balancing reciprocating parts between the several pairs of coupled wheels, instead of putting it on all the driving wheels, was not new. His old chief, the late Mr. Robert Sinclair, adopted that practice on the Great Eastern Railway some forty years ago. The weights were not distributed equally between the driving wheels and coupled wheels, but a considerable portion of the weight required to balance the reciprocating parts was applied to the wheels which were coupled to the drivers, and the results were in every way satisfactory.

Some remarks of Professor Dalby reminded him of an experience which he thought many members present would also have in mind, namely, that in the early days of locomotive balancing, the early "fifties," when the late Mr. D. K. Clark brought the question of balancing the reciprocating parts very prominently before locomotive men, the experience was that a large number of engines were over-balanced. It became understood that to get over the alternating pull on the train due to the action of reciprocating parts, it was necessary to balance the whole of the reciprocating parts, and many engines were so fitted. No slip resulted, because in those days the reciprocating parts of locomotives were very much lighter than they were now, even in proportion to the weight on the driving wheels; but a very unequal wear of the tyres was caused, and, as in those days iron tyres were used, that wear was very noticeable. Over forty years ago when he was head draughtsman in the locomotive department of the Great Eastern Railway, Mr. Sinclair instructed him to gather data on the point. Very careful templates were made showing the unequal wear of tyres produced by the over-balancing, and the result of the investigation was the conclusion that the utmost that could be satisfactorily balanced on non-coupled engines was five-eighths of the weight of the reciprocating parts. In the case of coupled engines rather more than that was balanced, and the necessary weight was distributed between the driving wheels and the coupled wheels. He remembered in 1862 he had a conversation on the point with the late Mr. Beyer, who stated that his firm had carried out some experiments on the subject, and had arrived at the conclusion that two-thirds of the weight of the reciprocating parts was the utmost that could be balanced in single engines, so that the practice of the present day was somewhat old as far as the amount of balancing was concerned. With the increased steam-pressure and the increase in the size of cylinders and consequently of working parts, a very much larger amount of hammer-blow had now to be dealt with. In those days there was nothing like the four tons Professor Dalby had mentioned. The question was therefore of increasing importance. The fact that a larger number of high-speed engines now had inside cylinders also brought another action into play, namely that, owing to the balance-weights not being in the plane of the cranks, there was a very considerable irregularity of pressure caused on the main bearings, and in some engines trouble had arisen from the unequal wear of those bearings. He had been informed by Mr. Hurry Riches that in some over-balanced engines a noticeable amount of ellipticity had been produced in the bearings, and that was a point on which perhaps some further information might be obtained in the course of the discussion.

Mr. Alexander McDonnell thought it was quite impossible for any person on the spur of the moment to enter into the discussion of so complicated a matter, and a matter which it was not possible to grasp very quickly. The balancing of locomotives was an old question, and in his own practice he had always followed out the arrangements which he believed were first brought into proper mathematical position by M. le Chatelier, who was the first person to show mathematically how to balance engines properly. He happened to know M. le Chatelier and often discussed matters with him, particularly with regard to the wear and tear of tyres caused by the different amount of balancing. It was so long ago that a good deal had escaped his memory, but he knew M. le Chatelier was exceedingly

(Mr. Alexander McDonnell.)

useful to him in suggesting the amount of balance that ought to be given; and, as well as he remembered, he balanced something about two-thirds. He did not think he ever balanced the whole amount. He also discussed the question very often with Mr. Beyer, and his opinions agreed to a very large extent with those of M. le Chatelier. When he first began balancing, his assistant was Mr. Parks, who preferred to experiment on the best balancing. Mr. Parks obtained permission to try some experiments without balancing at all, and the result was that he came back to the balancing. He found it was exceedingly disagreeable travelling on an engine that was not properly balanced; the engines got an exceedingly bad name, and therefore he changed his opinion with regard to the matter. It showed that a person who looked at a thing in a practical manner was quite capable of being convinced.

With regard to the hammer-blow, there had been sometimes some curious results. There was a case in Australia about which he was never satisfied. They tampered with the balancing of some of their engines, some of which were heavy, while some of their rails were light. Whether the rails were of good steel or not he could not tell, but he was informed on what he believed to be good authority that the rails were regularly broken by certain engines. There was no doubt whatever that the rails were broken, and broken at distances where the hammer-blow would have an effect upon them, distances of from 15 to 20 feet according to the diameter of the wheel of the engine. It certainly appeared to him to be very doubtful whether the hammer-blow could ever be so severe as to break a rail, although might bend one, unless the blow happened to come between two sleepers that were an unusually great distance apart, and the rail was very weak and of inferior steel, and ready to break with a little extra blow upon it. The matter was described very carefully, but he himself never saw any of the breakages or the distances that the breakages were one from another. But there was a large number of rails broken by engines which were badly balanced. The other engines properly balanced running over the same rails did not break them. The facts he thought were certain, but what it was that caused the curious breakage of the rails he was not able to satisfy himself about, or that it was entirely due to the non-balancing of the engine.

Mr. C. Humphrey Wingfield said that the author pointed out, if he understood him correctly, that although on a certain class of engine the wheel at one end of the crank-shaft might have its load so reduced (by the extra balance-weight necessary to counterbalance the reciprocating parts) that it was on the point of slipping, the wheel at the other end was safeguarded from slipping by the increased pressure on the rail.

Professor Dalby said it depended where the balance-weights were.

Mr. Wingfield referred to line 17 (page 1177), where it was stated that the engine might not slip, because the other wheel provided sufficient adhesion at the instant.

Professor Dalby said that was so.

Mr. Wingfield said that when that was the case, instead of the distribution on the crank-shaft being what it would be on the average if that action did not occur, the cheek of the crank nearest the wheel which adhered best might be taking the whole or very nearly the whole of the twisting moment, and it occurred to him that that might possibly account for some of the so-called mysterious breakages that had often puzzled locomotive engineers, as frequently repeated stresses of this kind might cause failure from "fatigue."

Mr. Druitt Halpin said the author had stated that, as far as the balancing system was concerned, bob-weights had never been adopted, but he thought that was an error, as the Germans had adopted it, according to what he had read about nine months previously in the proceedings of the German Society of Engineers. He drew attention to the fact that where the slipping took place, owing to the reduction of weights on the rails, due to the action of the counterbalances at high speeds, one of those cases arose where nature protected itself; the maximum adhesion was wanted at starting, and starting at slow speeds the diminution of adhesion due to counterbalancing did not

(Mr. Druitt Halpin.)

come in. In that way when the adhesion was most wanted the adhesion was most there. At high speeds the adhesion was decreased, but it was then less required. With regard to the broken rail question, he believed there were absolute investigations made in America with regard to small wheel coupled engines, by measuring the circumference of the wheel and by actually measuring where the engine broke the rail all along the road, in fact tracing the whole thing out. He could not give the reference, but he knew it was a fact, and one very difficult to explain or understand when one bore in mind that probably those same rails, say, 60-lb. rails, were put in 3-foot rigid supports, not on elastic sleepers, and that they would stand a blow of one ton falling 30 feet and reversed twelve times before the rail gave way.

Professor Robert H. Smith said the subject was part of a very complicated subject, that of locomotive driving in general. The author had frequently referred to coupling-rod effort, and most of his calculations had gone upon the supposition that the whole driving effort from the crank-shaft was transmitted to the three axles or two axles which were coupled together. It was difficult indeed to speculate fairly on how much of the real driving effort was transmitted through the coupling-rod, and it was that question which made the whole problem of locomotive driving an extremely difficult and complicated one. It was impossible to be certain as to what the coupling-rod was doing—what duty it was performing at each instant. Supposing that one of the coupled wheels in front of the crank-axle was worn only a very little more than the other wheel, so that its circumference was a little less, then at the same rotation of speed it would not travel the same distance along the rails by pure rolling, and it was clear therefore that it had to slip forwards, because it was compelled to rotate at the same average velocity as the other axles. That was to say, the coupling-rod effect was in this case supposed certainly such as to make the wheel slip forward, and while the coupling-rod was on the top part of the circle it would be in tension instead of in push. It would be in tension in order to drag backwards the top part and push forward the bottom part of the wheel over the rail. Throughout the lower half of the circle the coupling-rod would be in compression instead of in tension, as it ought to be if it were doing its fair share of the work. It seemed to him that the question of what share of the total work of the locomotive a coupling-rod was doing at each instant depended upon the non-uniformity or uniformity of the wear of the different wheels that were coupled together.

There was one other point which had not been noticed in the Paper, referring not so much to modern locomotives as to old locomotives in which the cylinder centre line was oblique to the horizontal. The question of hammer-blow depended to some extent, and in old locomotives to a very large extent, upon the obliquity of the centre lines of the cylinders. It was a question not simply of acceleration of masses, but also of steam-pressure. The steam-pressure was alternately in what might be called the upper or front end and the lower or back end of the cylinder, when the cylinders were not horizontal. The steam-pressures were internal forces, and at first sight one might be inclined to say that the internal forces could not possibly produce any effect in the variation of the pressure on the rail, which was an external force. But that was not so, because the frame and the masses resting upon it was one part of a locomotive, but axles and axle-boxes were another part not rigidly attached, the two being connected with springs. The steam-pressure coming into the front or higher end of the cylinder pressed forwards the front cover of the cylinder and all that was connected to it, naturally the great mass of the locomotive. At the same time it pressed with equal force the piston backwards and slightly downwards, but this force was transmitted, not to the same rigid mass as that to which the cylinder-power was attached, but to the axle and axle-boxes, which were separated by spring connections. That spring force between the two parts was a function of the relative positions of the two parts, and not at all of any steam-pressure in the cylinder. Thus when steam was suddenly let into the front end of the cylinder, there was an extra force heaving the whole mass of the locomotive upwards into the air, giving of course upward acceleration to that mass, while at the same time pressing the axles and wheels downwards upon the rail, an extra force equal to the vertical component of the steam-

(Professor Robert H. Smith.)

pressure upon the piston. That became modified as the frame moved upwards, but it was not so modified until the motion altered the geometrical strain of the springs, and thus altered the stress exerted by them. That he thought was a very serious part of the question of the hammer-blow, but did not apply to large modern locomotives with horizontal cylinders.

Mr. Arthur D. Jones expressed his obligation to Professor Smith for drawing attention to Fig. 12 (page 1179). He had ridden a good many hundreds of miles on that particular class of engine, and as he had not found them to slip as the diagram showed they would, he had intended to ask the author if there was not some chance of an error having been made. The 7 feet 3 inches four-coupled engines rode very well, and they had a very rough road to run on owing to the number of curves and quick changes of gradient and numerous junctions; there was no vertical oscillation on them. The ten-wheel passenger engine of the Atlantic type rode better still, but he did not think they were taken into account in the diagrams; the diagram he believed dealt with the eight-wheel engine, and with four-coupled wheels of 7 feet 3 inches diameter.

Professor Dalby said that was so.

Mr. Jones thought that all outside-running men would be very grateful to the author for raising the point with regard to slipping, as that was one of the worst things they had to contend with, especially in running through districts where there were a lot of chemical works. In a fog all the chemical refuse in the air seemed to be brought down to the rails, and made them very greasy.

The President asked whether Mr. Jones had noticed any irregularity in the wear of the tyres.

Mr. Jones could not say that he had.

Mr. J. Fraser Masterton said he wished to thank the author for the very able Paper he had written on a simple method of finding the amount and position of balance-weights in the wheels of locomotives. But he was a little surprised that no data were given whereby one could find the exact percentage of the reciprocating-weights, beyond that which was generally accepted as good practice, namely, two-thirds. Now, it appeared to him that, whereas if two-thirds of the reciprocating-weights were balanced in one class of engine it might be sufficient, while in another class it might be too much; it depended on the species of work in which the engine might be employed, whether goods or passenger. For instance, it was well known that if an engine (a "tank" for example) was unbalanced beyond that due to the coupling-rods—that was assuming they were opposite to the cranks—at a high speed the longitudinal motion would be very marked, and, as demonstrated by the author, if all reciprocating and revolving parts were balanced, intense "hammering" was produced. It would therefore appear that a mean required to be struck between these two, and this would depend upon the average speed of the engine. The author had made the most of the slipping question. It existed to an extent, but the amount depended on the nature and state of the road. While speaking upon slipping, he would like to know whether the author had taken into consideration the effect of negative slipping upon the crank-axle, if not, it would without doubt be an interesting study.

The President asked Mr. Masterton whether on the South Eastern Railway it was the practice to balance all the reciprocating parts on the driving wheels, or whether the necessary weight was distributed between two or more pairs of wheels.

Mr. Masterton said he distributed it. He drew attention to the fact that the author had not touched upon one important point, that known as back slipping.

Mr. F. V. Russell said the Great Eastern Railway Co.'s practice was to balance the engines in the way Professor Dalby had spoken of, that was to say, two-thirds of the reciprocating weights in a six-coupled engine would be distributed over the three wheels. As

(Mr. F. V. Russell.)
regards the revolving masses, those revolving about the driving-wheel axle were balanced in the driving wheel; those revolving about the leading axle in the leading wheel, and so on. Some of the older goods engines had all the reciprocating masses balanced in the driving wheels; on these engines that part of the tyre that transmitted the hammer-blow to the rail showed very great wear. In some cases the tyres had been eaten into, so to speak, quite half an inch at this spot. These engines had had a certain amount of the balance-weights taken out, and not much further trouble had been experienced. His company had a good many engines of that description without any balance-weights at all, the coupling-rods acting as a balance-weight to the connecting-rod, &c. Those engines with no additional weights in the wheel gave much better results than the engines which had two-thirds of the reciprocating masses balanced in the driving wheel. It was undoubtedly a mistake, especially in a small wheel engine to balance two-thirds of the reciprocating masses in the driving wheel. The wheels were about 4 feet 11 inches in diameter, and it had been found rather disastrous. The big four-coupled express engines with larger wheels, as well as the later type of goods engines, were balanced exactly in the way Professor Dalby had spoken about, and gave very great satisfaction.

Professor Dalby, in reply, said that with regard to the remarks made by the President, he might add something with respect to the effect of placing the balance-weights in planes outside the planes of revolution of the inside main cranks, that is between the spokes of the wheels. The transmission of the centrifugal force, due to the unbalanced revolving parts at each crank-pin, to the balance-weights was necessarily accompanied by a bending moment on the crank-axle. He worked out a case not very long ago in which the actual bending moment on the crank-axle, caused by the transmission of the centrifugal force from the crank-webs to the balance-weights, was as great as the bending moment produced by the greatest steam pressure ever brought to bear on the piston. Therefore although at high speeds the cut-off was early, and the turning moment was not anything like so great as it would be at starting, so that the straining actions on the crank-axle due to the steam pressures were relatively small, yet there was a large bending moment on the axle, due to the transmission of the unbalanced forces along the axle to the balance-weights. To eliminate this bending moment, it was necessary to balance the crank-webs and pistons in the planes of rotation of the main cranks. An example of this practice could be seen in the latest four-cylinder engines on the London and North Western Railway. There the crank-webs were extended forward and made into balance-weights, as used to be the case in marine-engine practice; in this way the crank-axle was relieved of a large amount of the bending moment, which was unavoidable with the usual practice.

He was interested to hear from Mr. McDonnell about the Australian episode (page 1192), where the rails were hammered out by the engine. He remembered reading about it some years ago, and he wanted to put the record in the Paper, but could not find it. He would be extremely glad if Mr. McDonnell could give him the reference. An account of the circumstance was he believed printed in "Engineering," but he could not find it. He would be glad if Mr. Druitt Halpin could refer him to any record of results of the German engines balanced by bob-weights or on the Yarrow-Schlick-Tweedy system. He thought he was right in saying that no engine had yet been balanced by the latter system in this country. He did not quite follow Professor Smith's remarks. There was no reference in the Paper to the proportion of the effort transmitted by the coupling-rods to the coupled wheels, except in the one case where it was stated that, if the couple resisting the slipping of the driving wheel was less than torque on the crank-axle, slipping would be prevented by the action of the coupling-rod. This was in connection with Diagram Fig. 12 (page 1179).

With regard to Mr. Jones's question (page 1196), he would point out that Diagram Fig. 12 referred to what would take place if the engine were running without its coupling-rod, that is, it only referred to a single-wheel engine, and it would be noticed that in his Paper he said (page 1179), "In the case in question, the coupled wheels would come into play and prevent it." Nowhere in

(Professor Dalby.)

the Paper did he make any suggestion, or require to make any reference, to the distribution of the work between the driving and the coupled wheel; and he was only concerned in the particular case, illustrated by Fig. 12, with the driving wheel itself.

With regard to Mr. Russell's remarks (page 1197), he was very glad to have such corroboration from one who was practically engaged in designing engines every day. With reference to coupled engines running without balance-weights in the wheels, he wished to emphasise Mr. Russell's point that, in a six-coupled engine of the ordinary type the coupling-rods themselves acted as balance-weights, and in fact they were used as balance-weights in Figs. 6 and 7 (page 1168). Therefore it was not true to say that a coupled engine, running without obvious balance-weights in the wheels, was running in an unbalanced condition. He thought that way of looking at it would account for the fact that some engineers had at times, on account of the wear of the tyres, had all the balance-weights pulled out, but they did not unbalance the engines, because the coupling-rod was left. In the first case the engine was over-balanced; in the second case it was supposed to be unbalanced, but it was to a certain extent balanced by the coupling-rod. He wished to thank the members present for the encouraging way in which they had received his Paper, and he hoped that the method therein explained would be of use to some of them.

Communications.

Mr. H. A. Ivatt, Member of Council, sent the following American rule for balancing outside-cylinder engines, which was formulated at the Master Mechanics' Convention in June 1896, and published in the "Railroad Gazette," 3rd July 1896.

(1) Divide the total weight of the engine by 400; subtract the quotient thus obtained from the weight of the reciprocating parts on one side, including the front end of the main rod,

(2) Distribute the remainder equally amongst all driving wheels, adding to it the weight of the revolving parts for each wheel. The sum will be the counterbalance required if placed at a distance from the wheel centre equal to the length of crank.

Note.—Assuming that the maximum speed in miles per hour of any driving wheel equals its diameter in inches, then forty times the portion of weight added to any wheel as balance for reciprocating weight must not exceed the static weight of such wheel on the rail, or the wheel will jump at such maximum speed. To ensure safety it should not exceed 75 per cent. of such pressure. Nor must this amount, when added to the static wheel-pressure, exceed the safe maximum pressure allowed on rails and bridges.

Mr. **Samuel Rendell** wrote that he thought the result of Professor Dalby's graphic method was identical with that obtained analytically by D. K. Clark in his "Railway Machinery," 1855. The moot question was: *How much* reciprocating weight should be balanced? Two-thirds had long been recognised, although a few have balanced three-quarters, or even the whole, and, it was said, with good results. The American Master Mechanics' Association recommended an amount equal to the total reciprocating weight on one side in lbs., less $\frac{1}{400}$th of the total weight of engine in lbs. The Americans balanced their engines, as if all the masses acted in the plane of the wheel. If each part were referred to its own plane, the weights would be larger and at a slight angle with the crank. In British-built engines this angle was commonly neglected, although it might easily be adopted with crescent-shape weights. If there was difficulty in making the balance sufficiently heavy, resort might be had to the American practice of casting the weight hollow and filling with lead. The reciprocating part of the connecting-rod might be determined by weighing the large and small ends on knife-edges. The two weights would give the centre of gravity of the rod. The path of the centre of gravity was an ellipse, in which the total weight might be represented by the major axis, the revolving weight by the minor axis, and the reciprocating weight by the difference between the two.

(Mr. Samuel Rendell.)

In an inside cylinder-engine one undesirable effect of the balance was to give rise to additional bending stresses in the crank-axle, and probably, in case of slipping, to considerable twisting also. The variation in the coefficient of adhesion was no doubt one of the chief causes of "flats" on tyres. Experiments were made with the locomotive at Purdue University* by passing lengths of soft iron wire, about $\frac{1}{32}$ inch diameter, under the driving wheel, when running at considerable speed on friction wheels. The wire was flattened, but not to uniform thickness, and at high speeds it was of its full diameter for a short distance, showing that the wheel had actually lifted. A locomotive, its largest mass resting upon springs, was a body subject to oscillation in various ways. At a particular speed the impulses of the unbalanced weights might synchronise with the period of oscillation in one or other of these ways, so that an engine which was steady at one speed might be very unsteady at another.

The writer was much impressed by an experiment made by Professor Osborne Reynolds of Owens College about twenty-two years ago. An adjustable model of a two-cylinder engine was mounted on a vertical steel wire. By arranging the cylinders and balance-weights as in a locomotive, and running at a gradually increasing speed, the model first oscillated gently by twisting the wire, and then with greater violence up to a certain point, after which the twisting subsided, and, at a still higher speed, was supplemented by a vertical hammering, which, in some conditions of balance, became at last so excessive as to shake the floor of the room. Doubtless this experiment had its parallel in locomotive running. These considerations all pointed to the desirability of making revolving and reciprocating weights as light as practicable. Until quite recently American pistons and crossheads were heavy in comparison with those designed in this country.

Mr. T. Hurry Riches, Vice-President, sent the following particulars of the method adopted upon the Taff Vale Railway for balancing their most modern locomotives. As he had instances of this class of engine running for five years without requiring the side-rod brasses to be closed, it would be realised that the wear and tear upon them was brought to a minimum; this he attributed mainly to the satisfactory balancing of the engines, as the work performed by these engines was as heavy as that done by any engines in England. They were fitted with single slide-bars.

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* Transactions, American Society of Mechanical Engineers, vol. xvi, December 1894.

TAFF VALE RAILWAY.

Six-coupled radial Passenger Tank Engine.

Inside Cylinder Single Engine, 17½ inches by 26 inches stroke.

DATA.

Distance centre to centre of cylinders	2 feet 2 inches.
Distance between the planes containing the mass centres of the balance-weights	4 feet 11½ inches.
Mass of unbalanced revolving parts per crank-pin reduced to 13 inches radius	604·3 lbs.
Mass of reciprocating parts per cylinder at crank-pin radius	718 lbs. (taken).
Proportion of reciprocating parts to be balanced . .	Three-fourths.

¾ of the weight due to the reciprocating parts	=	718·0 lbs.
Weight due to the revolving parts . .	=	401·3 lbs.
Weight to be balanced in driving wheel .	=	1119·3 lbs.

This worked out equal to 875 lbs. at 13 inches radius, but acting with counterbalance weight in wheel, they had the outside revolving weight, which was equal to 270·7 lbs.

$875 - 270{\cdot}7 = 604{\cdot}3$ lbs. at 13 inches radius.

$604{\cdot}3 \times 13 = 7{,}860$ moment of required balance-weight.

Driving Wheel, 5 feet 3 inches diameter :—

r	(see Fig. 3, page 1164)	18⅝ inches.
angle	ditto	19 deg. 47 min.
G	ditto	421 lbs.
i	ditto	16¾ inches.
j	ditto	42¾ inches.
k	ditto	59½ inches.
Equivalent mass at Crank Radius	. . . .	1,119 lbs.

(Mr. T. Hurry Riches.)

Leading and Trailing Wheels :—

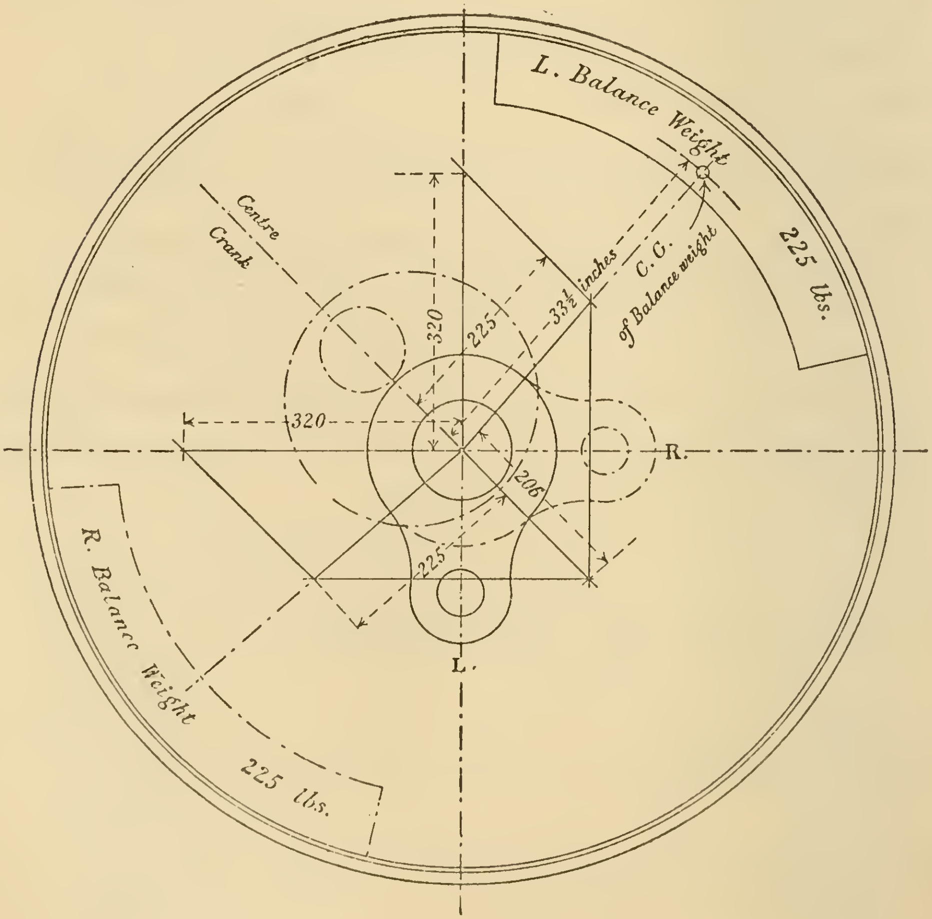
$$\left.\begin{array}{l}\text{Weight due to coupling-rod}\\ \text{,, \quad ,, \quad ,, outside crank-pin}\\ \text{,, \quad ,, \quad ,, boss}\end{array}\right\} = 187\cdot2\text{ lbs.}$$

Acting at 13 inches radius,
or 104 lbs. in wheel at 23⅜ inches radius.

The reciprocating parts are balanced entirely in the driving wheel.

The unbalanced masses of the leading and trailing wheels are wholly revolving, and are therefore entirely balanced ; they consist of the crank, boss, crank-pin, and washer, and a proportion of the coupling-rod.

Fig. 23. *Three-Cylinder Locomotive.*
Graphic method of finding resultant Balance-Weights.



Mr. Walter M. Smith, of Gateshead, wrote that the balancing of locomotives chiefly concerned locomotive engineers, and that any subject in connection with the advancement of the locomotive engine, seeing how little it had really advanced compared with other branches of engineering, should be accorded a hearty welcome by all. Although there was nothing very novel in the balancing of locomotives, much credit was due to the author for the very able and interesting manner he had explained and illustrated his subject. No example had been given in connection with the balancing of a three-cylinder locomotive. The writer, therefore, begged leave to give one, which had been got out by him in connection with a three-cylinder locomotive, Fig. 23 (page 1204).* This method had been found in practice all that there was to be desired, the locomotive running absolutely steady at any speed. The weight to balance the revolving and reciprocating masses was found in the usual way, and was for the inside cylinder, 206 lbs., the centre of gravity being 33·5 inches from the centre of the wheel, and that for each of the outside cylinders 320 lbs., and the resultant balance-weight 225 lbs.

Mr. Oswald Wheeler wrote that there was another method than the one by which the author proposed to prevent the side-way waggle of a locomotive. It was to use a pair of cylinders on each side, with a link from each crosshead to a triangular connecting-rod on the crank-pin, Fig. 24 (page 1206). It would be seen that there was no dead-centre; and as each upper or lower cylinder pulled or thrust at the same time as its fellow on the other side, there was no unbalanced force to work the frame from side to side. The triangular connecting-rod was not new by any means, but it was quite an independent invention of the writer's. He arrived at it when trying for a simple arrangement of compound locomotive. As such it was worth consideration, for both high-pressure cylinders acted together so that their full power was available for starting, and as there was no dead-centre the engine would start easily. Also only two sets of valve gear were needed. The connecting-rod acted as a rocking

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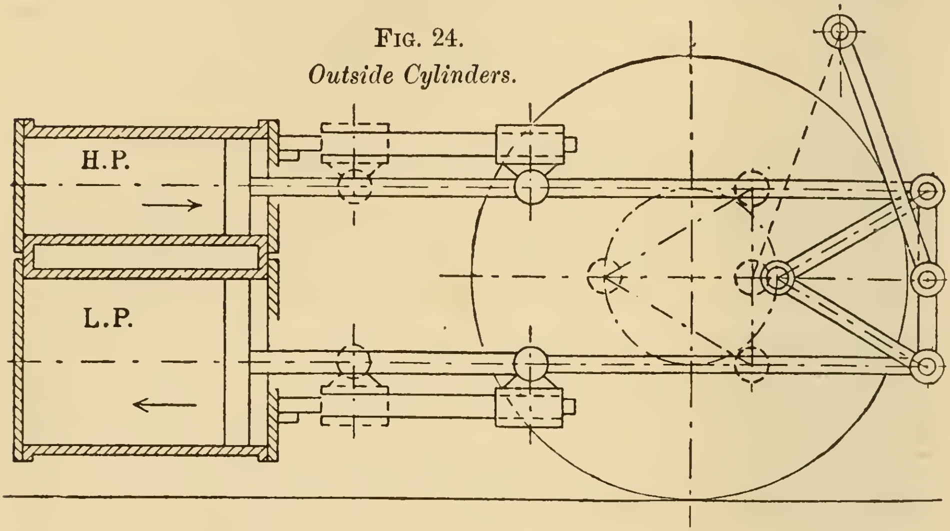
* "Engineering," 5th July 1901, pages 8, 13, 14, 15, and 16.

(Mr. Oswald Wheeler.)

lever at the ends of the stroke, and the reciprocating parts were then in balance. During the rest of the stroke the effect of the two pistons was equal to two cranks about 100° apart, and the reciprocating parts did not balance each other; but no doubt the correct weight to put in each driving-wheel could be found by the simple and ingenious method so ably expounded by Professor Dalby.

Fig. 24.

Outside Cylinders.



Professor Dalby, in reply to the written communications, wrote that the American rules given by Mr. Ivatt (page 1200) were very interesting. Considering the first rule, it followed that when the weight of the reciprocating parts per side was $\frac{3}{800}$ of the total weight of the engine, two-thirds of the reciprocating parts would be balanced if the rule was used. A less proportion than this would be balanced, if the weight of one set of parts was greater than $\frac{3}{800}$ of the total weight, and a greater proportion than two-thirds if they weighed less than this amount. The second rule seemed to indicate that in America the reciprocating parts were under no circumstances balanced entirely in the driving-wheel, if the engine was coupled. The assumption in the note to the second rule—namely, that the maximum speed in miles per hour of any driving-wheel equalled its diameter in inches—was equivalent to fixing the maximum number of revolutions per minute of the driving-axle of all engines at 336. This corresponded to a maximum piston speed of 1,344 feet per minute for a 2-foot stroke. If w is the mass in pounds or tons placed in any one of the coupled wheels to balance a part of the reciprocating mass, the centrifugal force due to this at the limiting speed of 336 revolutions per minute reduces to $38 \cdot 5\, wr$, lbs. or tons weight as the case might be. Hence, if $r =$ one foot, the wheel would be on the point of lifting if the static load on the wheel were $38 \cdot 5$ times portion of the balance-weight in any one wheel added to balance the reciprocating parts.

He thought that Mr. Rendell was right in thinking that the author's graphic method gave the same result as the analytical method given in D. K. Clark's "Railway Machinery." In fact, let them once settle the amount of the reciprocating parts to be balanced, and the method merely discovered the answer in what he believed draughtsmen would find an easier and more convenient way than any purely analytical method. With respect to the question: How much of the reciprocating parts should be balanced ? the proper reply was—as much as possible. But since in a two-cylinder engine whatever was balanced horizontally only appeared again vertically in the form of a hammer-blow, the proportion must not be greater than that required to keep the hammer-blow within reasonable limits for the sake of the bridges and the permanent way, and to be sure that there was no danger of the balance-weight lifting the wheel clear of the rail at high speeds. In a four-cylinder engine undoubtedly the proper answer was—balance all the reciprocating parts completely. The rule of the Master Mechanics' Association mentioned was the same, he believed, as that quoted by Mr. Ivatt. The path of the centre of gravity of a connecting-rod was hardly an ellipse, unless, as he presumed was the case, Mr. Rendell assumed the connecting-rod to be infinitely long.

The information given by Mr. Hurry Riches of the practice on the Taff Vale Railway was so clear and concise, that it was quite unnecessary for him to say anything on it.

With reference to Mr. Walter M. Smith's interesting communication (page 1205), he would like to have included an example of balancing a three-cylinder engine in the Paper, to show that the method he had explained was quite general, and might be applied to any number

(Professor Dalby.)

of cranks at any angles amongst themselves and connected to reciprocating parts of different weights. He had had no actual data by him, and as the Paper was getting too long he made no effort to obtain any for publication. An example of the balancing of a four-cylinder engine, including the valve gear, would be found in "Engineering" of 21st April 1899.

The author's method of computation could hardly be applied to the type of engine described by Mr. Oswald Wheeler (page 1205), and illustrated in Fig. 24 (page 1206), because the motion of the pistons was very different from simple harmonic motion. He might point out that it was not at all certain that there would be no dead-centre in the arrangement shown. The arrows placed on the high-pressure and low-pressure cylinders indicated the direction of motion only, and not the direction of resultant steam-pressure. In the position shown, for instance, the arrow on the high-pressure cylinder representing the direction of pressure would be pointing in opposition to the direction of motion of the piston, because of the compression. Hence, it might easily happen that both pistons were pulling with equal force, in which case there would be no turning effort on the crank, if it happened to be in the position shown in Fig. 24.

The Institution of Mechanical Engineers.

PROCEEDINGS.

December 1901.

An Ordinary General Meeting was held at the Institution on Friday, 20th December 1901, at Eight o'clock p.m.; William H. Maw, Esq., President, in the chair.

The Minutes of the previous Meeting were read and confirmed.

The President said he had much pleasure in announcing that Mr. Watson-Armstrong had presented to the Institution a very beautiful and effective portrait of Lord Armstrong, which had been hung in the Reading Room. At their Meeting that afternoon the Council had unanimously accorded a vote of thanks to Mr. Watson-Armstrong for his gift, and the President, feeling sure that the Members would wish to share in the action of the Council, asked those present to endorse that vote of thanks with acclamation.

This was carried with applause.

The following Paper was read and discussed:—

"The Microscopical Examination of the Alloys of Copper and Tin"; by Mr. William Campbell, B.Sc. (Durham), of Columbia University, New York, and late of the Royal School of Mines, London.

The Meeting terminated at Ten o'clock. The attendance was 82 Members and 84 Visitors.

THE MICROSCOPICAL EXAMINATION OF THE ALLOYS OF COPPER AND TIN.

(Being an Appendix to the Reports of the Alloys Research Committee.)

By Mr. WILLIAM CAMPBELL, B.Sc. (Durham),
of Columbia University, New York,
late of the Royal School of Mines, London.

The following research was made in the metallurgical laboratory of the Royal School of Mines, London, with a view to explain the complete freezing-point curve of the copper-tin alloys published in the Fourth Report of the Alloys Research Committee,* and to note the change of structure due to casting.

The microstructure of the copper-tin alloys has been studied by Behrens, Charpy, Stead, and others. Behrens divides these bronzes into two principal groups: bronzes rich in copper, containing from 1 to 25 per cent. of tin, and bronzes rich in tin containing over 25 per cent. of tin. With the exception of the metals for mirrors (25 to 35 per cent. of tin) which appear homogeneous, Behrens says that in all bronzes a portion richer in copper or richer in tin may be detected, forming the fundamental mass, the former in alloys rich in copper, the latter in those rich in tin.†

Charpy divides them into those rich in copper, containing 100 to 73 per cent. of copper; and those rich in tin, which latter are again subdivided into four groups: 0 to 3 per cent. of copper, in which tin crystallizes in the matrix; 3 to 55 per cent. of copper, in which a compound of tin and copper crystallizes out of the matrix; 55 to 65 per cent. of copper, which have a structure quite homogeneous and difficult to resolve; and 65 to 73 per cent. of copper, in which hard white grains crystallize in the higher eutectic.

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* For First, Second, Third, Fourth, and Fifth Reports, *see* Proceedings 1891, page 543; 1893, page 102; 1895, page 238; 1897 page 31 and 1899, page 35.

† Metallographist. Vol. i., page 193.

The curve of fusibility, as determined by Le Chatelier, is composed of three branches, forming by their intersections two points which correspond with alloys containing 3 and 72 per cent. of copper.

0 to 3 per cent. of copper: straight: fall.
3 „ 72 „ „ uniformly curved: rise.
75 „ 100 „ „ almost straight: rise.

The meaning of the curve is seen to be as follows. Alloys containing 0 to 3 per cent. of copper consist of tin and of tin crystallizing in more and more eutectic. At the point where the two branches meet occurs the first or lower eutectic. Above this point, bright slender porphyritic crystals form, and their number increases till at 61·8 per cent. they form a uniform mass, probably a definite compound $Sn\ Cu_3$. At 68·28 per cent. of copper the alloy is again found to be homogeneous,* and is probably another definite compound $Sn\ Cu_4$. Between these two points, the alloys seem to consist of $Sn\ Cu_3$ and $Sn\ Cu_4$, separately solidified, the latter in the former. From 68·28 per cent. of copper to 72 per cent. we pass from the compound $Sn\ Cu_4$ to the second eutectic. Above 72 per cent. the copper crystallizes out in the eutectic as yellow dendrites, and then as skeleton crystals, which increase in number and size until at 100 per cent. they occupy the whole mass.

If, however, we study the complete cooling curve of the Copper-Tin Alloys,† by Sir William Roberts-Austen, reproduced in Fig. 1 (page 1214), it is seen that the meaning of only a part of the curve has been explained above. The branches *c*, *e*, and *f* remain unaccounted for.

The result of the microscopical study of these alloys is shortly as follows:—

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* Roberts-Austen. An Introduction to the Study of Metallurgy, page 99; Laurie. Journal of the Chemical Society, Transactions, vol. liii, 1888, page 104.

† An Introduction to the Study of Metallurgy, page 70; Fourth Report of the Alloys Research Committee, Proceedings 1897.

When 1 per cent. of copper is present, the first eutectic alloy is obtained, that is, the one with the lowest freezing-point; and between pure tin on the one hand, and this alloy containing 1 per cent. of copper on the other, tin is found crystallizing in the eutectic, first in grains, then in dendrites.

When the percentage of copper is increased above 1 per cent., thin bright needles are seen, which increase in size and number, and vary in their method of grouping, until 8 per cent. of copper is reached. According to Stead, their composition also varies, increasing in copper (from Cu Sn) as the total percentage of copper in the alloy increases.*

A third constituent is seen when the copper exceeds 8 per cent. We have the eutectic or ground-mass enclosing the bright porphyritic crystals, but these bright crystals are seen in places to have grown on and around a different kind of crystal, which is easily distinguished from the rest because it turns black when exposed to the air for any length of time. It is not a case of one crystal varying in composition from the centre to the faces; for a sharp line of junction can be seen between the two constituents. As the percentage of copper is increased, the more easily oxidized central crystals increase in number and size, whereas the bright outer crystals begin to diminish together with the eutectic. Therefore it would appear that in alloys containing more than 8 per cent. of copper the first constituent to crystallize out is the easily oxidized central crystals. This causes the first halt in the cooling curve *a b*. Then the bright crystals solidify, causing the second halt, on the branch *f*. Lastly the eutectic solidifies, and the third halt is reached, on the branch *g*. As branch *f* is horizontal, it would seem that the bright crystals have a definite composition when above 8 per cent. of copper is present in the alloy; but when the branch *f* joins the outer curve *b a*, and falls to *b*, these crystals no longer have a definite composition, and their percentage of copper falls. The following is the analysis of the crystals, which agrees very nearly with that given by Stead:—

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* Journal, Society of Chemical Industry, June 1897, page 506.

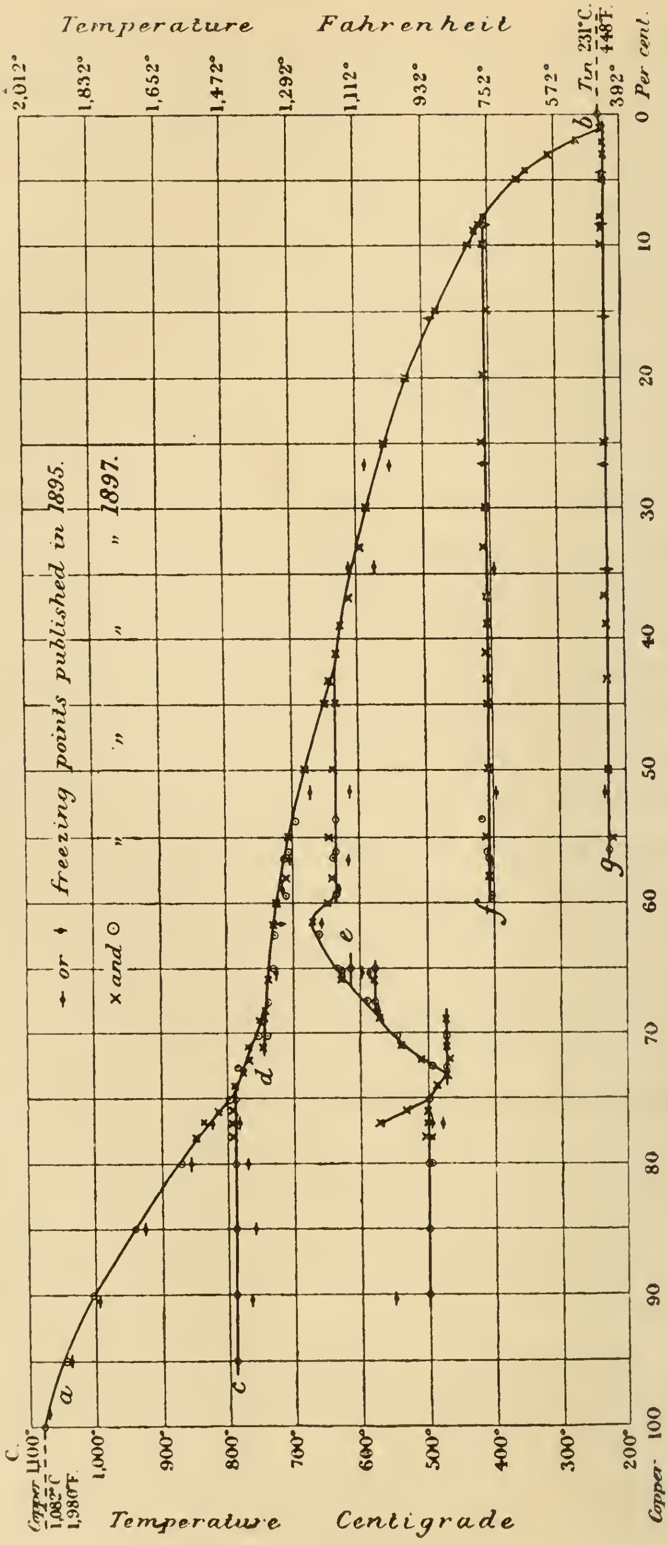


FIG. 1.—*Freezing-point Curves of Copper-Tin Alloys, reproduced from Plate 10 of Fourth Report, 1897.*

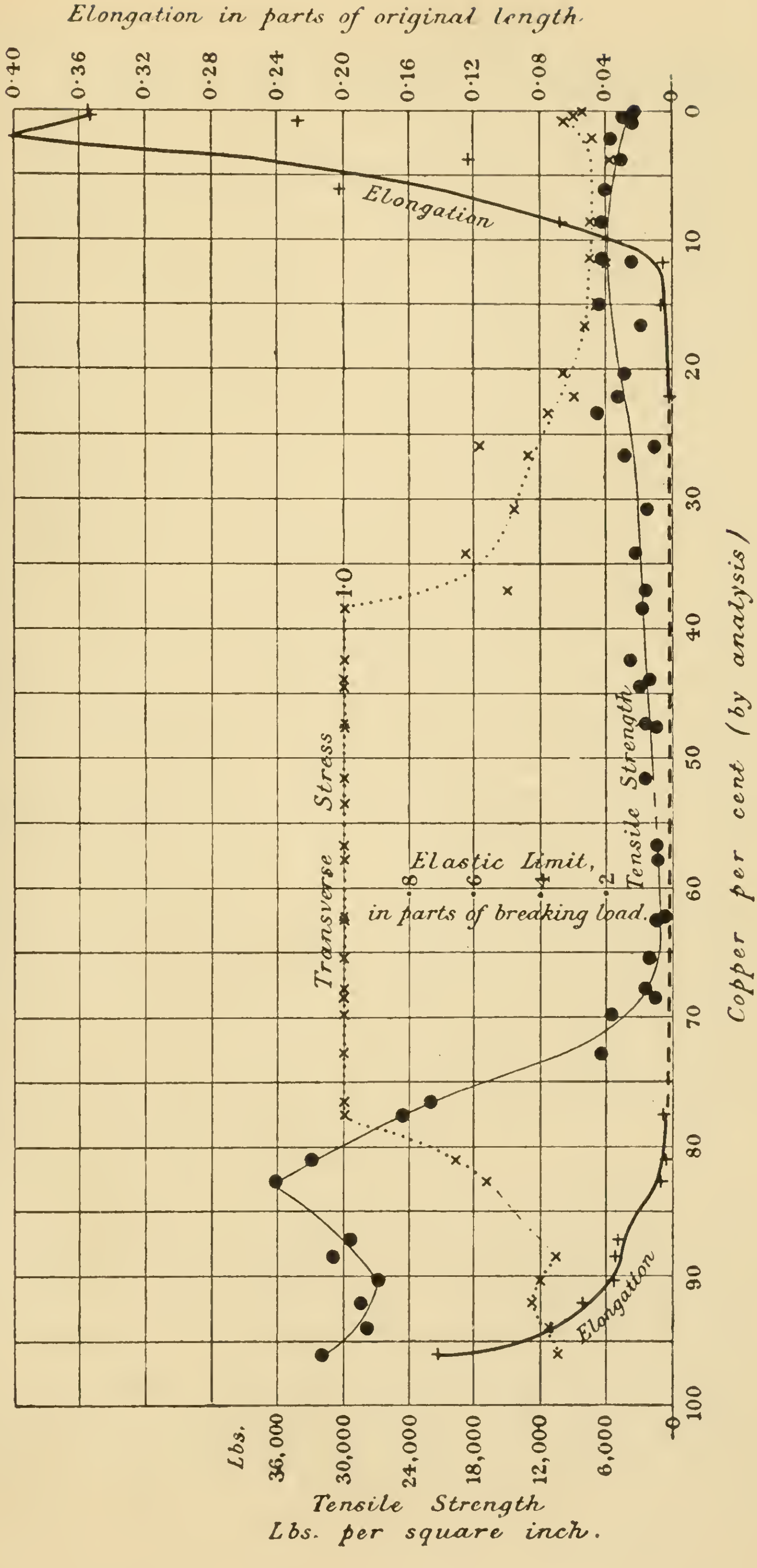
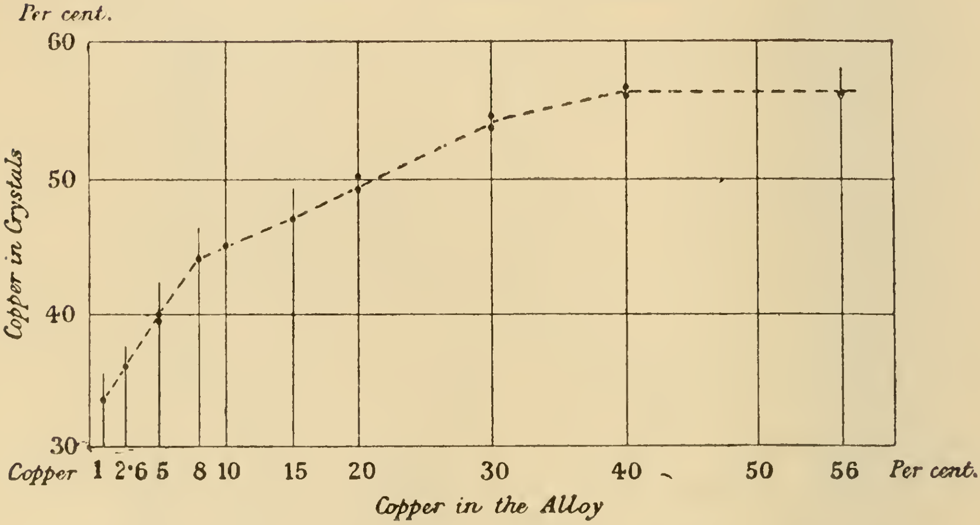


Fig. 1a.—*Tensile Strength, Elongation, and Transverse Stress of Copper-Tin Alloys.*
(Plotted from "Alloys Brasses and Bronzes," Thurston, Part 3, Table LXV., pages 342–3.)

	Per cent.		Per cent.	
Alloy contained	1	copper, crystals contained	33·5	copper.
„ „	2·6	„ „ „	36	„
„ „	5	„ „ „	40 39·5	„ „
„ „	8	„ „ „	44	„
„ „	10	„ „ „	45	„
„ „	15	„ „ „	47·2	„
„ „	20	„ „ „	49·2 50·2	„ „
„ „	30	„ „ „	53·5 54·5	„ „
„ „	40	„ „ „	56 56·5	„ „

FIG. 2.—*Composition of Crystals.*



The variation of 1 per cent. in several of the analyses is due to the difficulty in getting rid of any oxide of tin, entangled amongst the crystals, without dissolving out any of the constituents of the crystals.

If a curve be plotted showing the relation between the percentage of copper in the alloy and the percentage of copper in the crystals, a straight line is obtained from 1 to 8 per cent. of copper in the alloy, but at 10 per cent. the crystals are quite away from this line, Fig. 2.

With 41 per cent. of copper in the alloy, there is a distinct change in the character of the alloy, Fig. 1 (page 1214). The addition of 1 per cent. of copper has changed the composite crystals from large plate-like masses to small lath-like rods, surrounded as before by the bright constituent. As the percentage of copper in the alloy increases, the eutectic diminishes, and at 56 per cent. disappears *: the central and more easily oxidizable portion of the composite crystals steadily increases, and the bright constituent decreases, until 61·7 per cent. of copper is reached, when the whole mass appears to be uniform. This is the alloy $Sn\ Cu_3$.

From 61·7 to 68·28 per cent. of copper, Fig. 1, the higher compound $Sn\ Cu_4$ crystallizes out round or alongside of decreasing proportions of $Sn\ Cu_3$, till at 68·28 per cent. the alloy is uniform throughout, and is probably another definite compound. The difference between these two compounds is very marked; that containing the 68·28 per cent. of copper is harder, of lighter colour, and less easily attacked by acids. It is extremely brittle, and when quenched it flies to pieces. It is remarkable for the high degree of polish which it takes. The lower compound $Sn\ Cu_3$ on the other hand has a marked cleavage.

From 68·28 to 74 per cent. of copper, where the second eutectic of the series occurs, Fig. 1, the alloys are seen to consist of the bright $Sn\ Cu_4$ surrounded by eutectic. They are generally granular, and the borders of each grain or crystal consist of bright $Sn\ Cu_4$, while the centre is occupied by $Sn\ Cu_4$ as dendrites or grains set in the eutectic. The amount of the eutectic increases with the increase of copper, until it occupies the whole mass.

The part of the curve of solidification, *b a*, is seen to be a continuous rise from 68·3 to 74 per cent. Cu, and the 74 per cent. alloy has a higher freezing-point than $Sn\ Cu_4$. Hence if 74 per cent. be a eutectic, it must have formed when the alloy was solid. The third branch *e* of the complete cooling curve resembles an ordinary cooling curve having two branches inclined to each other and a horizontal branch at their intersection, which occurs at about

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* Stead. Journal, Society of Chemical Industry, June 1897, page 506.

74 per cent. Seeing that this branch *e* passes through the series from 90 to 41 per cent. of copper, it appears probable that at 41 per cent. the change in the alloy is simply one of arrangement. Since the alloys with 68·28 and 61·7 per cent. of copper, though seemingly compounds, have at least two distinct breaks in their cooling curves, it would appear that branch *e* in part, if not wholly, represents a rearrangement after solidification, and resembles the lower curve (Ar_1) for the carbon-irons.* So it would seem that in this division of the series the alloys solidify as a whole at the upper break in their cooling curve; but that, when they cool down, a re-arrangement takes place, and the formation of dendrites of $SnCu_4$ is obtained in the second eutectic. The eutectic alloy solidifies as a whole at about 780° C. (1,440° F.), but at 480° C. (896° F.) its structure changes to that of a eutectic.

In the discussion following the admirable Paper † on the Quenching of Copper-Tin Alloys, by Messrs. Heycock and Neville, at the Royal Society, it was pointed out that the present author had attempted to settle this question by quenching (in cold water) several of the furnace-cooled alloys which had been reheated to 700° C. (1,290° F.) This temperature proved to be below the melting point of each of the alloys so treated. The 73 per cent. alloy was first examined. It was found that the original structure had been entirely destroyed in the treatment, and the new structure was very similar to that of the alloy when cast. That is to say, the bright dendrites and veins in the eutectic are only distinguished under some 300 diameters magnification. The 71 per cent. alloy gave the same result, only more marked. When the 68·3 per cent. alloy was thus treated, it became so brittle and strained that on standing it broke up into fragments. On etching and examining the fragments, the original structure was missing. The 66 per cent. alloy also gave the appearance of having been cast. No trace could be seen of anything like a eutectic such as had been observed in the original alloy. On quenching the 61 per cent. alloy it broke up, though not to the extent of that containing 68·3 per cent. of copper. The large crystallization characteristic of the original alloy was destroyed. This method of treatment could not be used below 61 per cent. of copper because, when the tin rises above 40 per cent., the bright constituent, which solidifies out about 400° C. (720° F.), comes in, and therefore re-heating to anything like 650° C. (1,170° F.) would melt part of the alloy.

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* Stansfield. Present Position of Solution Theory: Journal, Iron and Steel Institute, 1899, Part II, page 169; also Proceedings 1899, Plate 5.

† Proceedings, Royal Society, vol. lxviii, page 171.

From the above it is seen that, between 74 and 60 per cent., re-heating the furnace-cooled alloys to 700° C. (1,290° F.) does not melt any portion of them, and that quenching at that temperature causes a new structure, which, in each case under examination, was similar to that due to casting.

It was naturally concluded that, if these quenched alloys were annealed at about 700° C. (1,290° F.) and slowly cooled, the effects of quenching would be obliterated, and the normal structure would be restored. The 73 per cent. Cu alloy which had been quenched was placed in a porcelain cup, covered with powdered charcoal to prevent oxidation, and annealed in a muffle for a short time. The muffle was then allowed to cool, and the alloy examined. The change was incomplete, part of the alloy being in a transition state. In all parts the effects of quenching had disappeared, and in several places the normal structure had been quite restored, and the usual bright dendrites were seen in the eutectic. This transition state showed clearly how the change had taken place. Large bright grains separated from each other by a darker material (the eutectic) were seen, and gave the alloy the appearance of a decomposing rock. In places these bright grains were splitting up into dendrites and eutectic: so that the whole series of structures, from that of the bright granular material on the one hand to that of the normal dendrites on the other, could be clearly followed. Hence it seems that the true explanation of the branch *e*, between 68·28 and 61·7 per cent. of copper is that it is one of re-arrangement in the solid.

When the copper is increased above 75 per cent., the colour of the alloy changes sharply from a bluish tint to a distinct yellow. A new constituent appears, consisting of rounded yellow grains. This has crystallized out first, and then a bright white substance has formed round the yellow grains and in the eutectic. It seemed probable that at about 790° C. (1,454° F.) the mass solidified entirely round the yellow grains, and that at a lower temperature it re-arranged itself into bright grains and eutectic. To test this point a 76 per cent. furnace-cooled alloy was re-heated to about 700° C. (1290° F.) and quenched. No sign of melting was noticed. On examination the grains of copper were found to be unaltered, but the structure of the eutectic and the bright grains had completely disappeared. The eutectic appeared to be in the form of large grains, in which the bright constituent had solidified like a 73 per cent. alloy. Therefore it may be assumed that branch *c* represents a solidification of the whole mass, and *e* a re-arrangement in the solid.

With the increase of the total copper in the alloy, the yellow grains increase, forming dendritic skeletons, and altering in colour from yellow to red as pure copper approaches. The change of colour is due to the fact that the dendritic copper contains some tin in solution, which gradually disappears, and hence the colour changes from yellow to red. For the same reason the temperature of solidification of the copper dendrites increases. The same thing occurs in the Copper-Antimony Alloys.*

Between 90 and 95 per cent. the eutectic disappears, and between 95 and 100 per cent. the bright borders merge into the dendrites of copper.

Hence from 75 to 100 per cent. of copper the outer curve from *c* to *a* represents the solidification of the yellow dendrites and grains, which at first contain some tin but finally become pure copper. The horizontal branch *c* denotes the solidification of the remainder, which, when between 75 and 90 per cent. Cu is present in the alloy, re-arranges itself into a bright constituent in the form of grains and borders surrounding the yellow dendrites, and into eutectic; and this change is marked by *e* in the cooling curve.

Change in Structure due to Casting.—When the alloys which contain between 0 and 1 per cent. Cu are cast, the tin crystallizes out as grains very much smaller than those of the slowly-cooled alloys. The proportion which the grains bear to the eutectic is greatly increased by casting; and this seems to point to the fact that in cooling quickly the grains of tin retain some copper. On the other hand, no crystals can be seen in the 1 per cent. alloy when cast, whereas when it is slowly cooled in the furnace they are present. Thus the eutectic contains slightly more copper when cast than when slowly cooled.

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* Stead. Journal, Society of Chemical Industry, December 1898, page 1111.

When from 1 to 8 per cent. of copper is present, casting produces a fine network of bright crystallites throughout the eutectic. On treatment with 10 per cent. nitric acid and washing with dilute hydrochloric, the eutectic is dissolved, and a fine dark brown powder is left behind, which seems to be composed of very small shapeless plates. The crystallites form well-defined skeleton crystals, of which the component parts thicken with the increase in copper. The 10 per cent. alloy shows no sign of a third constituent, although, when a 9 per cent. alloy was cast in a pasty condition, the third constituent could be clearly seen, forming the core of some of the bright crystals. In this case many of the bright crystals possessed their characteristic form.

The 20 per cent. Cu alloy is composed of bright rod-like crystals, which, under a magnification of some 300 diameters, are seen to be composed of two constituents, as in the slowly-cooled alloy. These rods increase in size as the copper is increased to 40 per cent. The various residues, after treatment with dilute nitric acid, become more and more coherent, until at 40 per cent. a spongy skeleton is left behind. With 41 per cent. of copper the crystals change in character, and become more or less fibrous in appearance, whilst beautiful structures are seen on the surface of the alloy. But little eutectic can be seen; and when the copper is increased to about 50 per cent. no eutectic can be distinguished, the alloy being apparently composed of the bright and dark constituents only. The bright surrounds the dark as a matrix. As the copper in the alloy is increased, the bright constituent diminishes and finally disappears at about 61 per cent.

Between 62 and 68 per cent. Cu the alloys present a striking appearance when cast. They consist of the bright constituent, probably $SnCu_4$, intersected by veins and parallel lenticular bands of the dark material. There is no trace of the eutectic-like structure. When the alloy is near 61·7 per cent. Cu in composition, there is naturally but little of the bright constituent, which surrounds the grains of the dark material like an envelope. The appearance is similar to that of the alloy when slowly cooled, but more minute. It would seem probable that, if the cooling could be performed with sufficient rapidity, the resultant alloys (between 62 and 68 per cent.) would give a series, in which each consisted of a single constituent: that the character of the series would vary from that of $Sn\ Cu_3$ to $Sn\ Cu_4$ quite uniformly. In other words, the separation into two constituents would be prevented. The 68 per cent. alloy when cast appears to consist of polygonal grains of varying size and with bright borders. When deeply etched, and examined under a magnification of some 2,000 diameters, the grains are seen to be composed of systems of bright and dark parallel laminæ, the whole closely resembling a eutectic. Amongst some of the bright laminæ or dendrites there is a distinct tendency to form skeleton crystals, whose form is quite distinct from those seen in the slowly-cooled alloy.

Between 68·28 and 74 per cent. of copper the structure is granular, the mass being made up of polygonal grains. Two constituents can be seen, one bright, the other dark. The bright forms round the edges of the grains, and appears like radiating lines. Under high magnification bright grains and dendrites can be seen in the dark constituent, which is the eutectic. The 74 per cent. alloy is made up of grains, each of which has a particular orientation, thus giving the alloy a speckled appearance. Only under very high powers can its eutectic nature be discovered.

At about 76 per cent. Cu the copper dendrites and grains make their appearance. They are very minute, and it is hard to distinguish between them and the bright constituent which surrounds them.

In the 80 per cent. Cu alloy the dark dendritic crystals of copper can clearly be seen, forming parallel groups. It is quite clear, by comparing the proportion of copper dendrites and grains in alloys of the same composition—the one cast, the other slowly cooled—that the dendrites in the cast alloy must contain more tin than in the slowly cooled. Charpy points out that in quickly-cooled alloys the eutectic may even disappear, notwithstanding the presence of some 7 to 8 per cent. of tin; and he considers the bright borders and grains to be part of the eutectic. The effect of oxidation, when this occurs, shows that the dendrites vary in composition from centre to border. The surface structure of the alloys between 80 and 100 per cent. Cu is often very fine, and generally consists of numbers of distinct skeleton crystals, which stand out prominently above the surface.

The result of casting, therefore, is always to make the structure comparatively minute. In alloys rich in copper, the dendrites of copper contain more tin when cast than when slowly cooled. Similarly in those alloys containing dendrites of tin, the tin probably tends to retain more copper when cast. Again, casting tends to raise the percentage of copper in the first eutectic, and probably also in the second. Lastly, it seems that $Sn\,Cu_4$ when cast has a different crystalline form from that which it possesses when slowly cooled.

During January 1901 a recording pyrometer was set up in the Metallurgical Department of the Royal School of Mines, and this offered a means of verifying the results obtained by annealing. The pyrometer was first made to give the cooling curve of the particular alloy under treatment, after which the alloy was quenched at different temperatures, corresponding with particular points on its cooling curve. Sections were made from the quenched alloys, and examined in the usual way.

A description of the pyrometer is hardly necessary here, but Plate 189 shows a front and back view and the pyrometer in place. In Fig. 5 the recorder* is seen on the left-hand side, whilst the galvanometer circuit is seen on the right. The galvanometer is a "dead-beat," and stands on a shelf let into the angle of the wall, thus making it quite rigid. The beam of light emerges from a slit in the casing of an incandescent electric light, fixed at the side of the recorder; by means of a single lens it is focussed upon the mirror of the galvanometer, whence it is reflected back to the slit and scale of the recorder. Both galvanometer connections pass to the cold junction of the thermo-couple, one direct, the other by way of a post-office resistance-box. The cold junction is seen on the upper shelf on the right, and from it proceed the wires of the thermo-couple. By means of the resistance box the temperature readings of the scale on the recorder can be varied at will.*

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* Designed by Dr. A. Stansfield.

The alloy was melted in a small crucible, placed inside a larger. The inter-space was filled with asbestos fibre, and in this way slow cooling was obtained. The average time of fall from 1,000° C. to 500° C. (1,800° F. to 900° F.) was half-an-hour, which was found to be a sufficiently slow rate to admit of the alloy being quenched exactly at the right temperature. When liquid, the alloy was removed from the fire, together with outer crucible and lid, and placed upon two bricks on the table. The thermo-couple, covered with its clay case and mica insulation, was then pushed through a hole in the lid into the molten metal. It was soon found that, if the thermo-couple was not kept well down in the alloy, the readings obtained were too low. When the spot of light on the scale reached the desired temperature, the wires of the thermo-couple were quickly withdrawn from the clay tube, and the inner crucible and alloy were plunged into cold water. Each of the alloys treated was quenched both when in the liquid state and also at the moment of complete solidification; this point is never less than 685° C. (1265° F.) in alloys containing more than 61 per cent. Cu.

The following results were obtained :—

50 per cent. Cu, 50 per cent. Sn. The cooling curve showed four breaks, namely 680°, 635°, 410°, and 225° C. (1,256°, 1,175°, 770°, and 437° F.)

As the last two have been explained, they were not taken into consideration.

When quenched liquid, the alloy had a granular appearance. The grains were small, and were enveloped in a darker material, probably the eutectic. Etching failed to bring out any structure in the grains themselves.

Quenched at 650° C. (1,202° F.), which is below break 1, the alloy showed a granular appearance, much larger than the above. The dark enveloping matrix had increased in quantity, and the grains showed a tendency to form dendrites. Besides the large grains and matrix, patches of very fine grains were seen on etching the specimen. It is possible that they represent the bright constituent which crystallizes out in the 1 up to 8 per cent. alloys.

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* Proceedings 1891, page 546.

When quenched below break 2, at 600° C. (1,112° F.), the structure was found to have changed considerably. Although more or less granular in parts, the grains appeared to be crystals cut across their main axis. The alloy was distinctly crystalline in the hand-specimen, and under the microscope each crystal was seen to be composed of numbers of parallel squat laths. These could not be distinguished into two constituents, as in the case of the slowly-cooled alloy; but their form closely resembles that in the slow-cooled specimen.

66 per cent. Cu, 34 per cent. Sn. Three breaks at 740°, 635°, and 580° C. (1,364°, 1,175°, and 1,076° F.)

The appearance of the alloy which has been quenched when liquid is the same as that of the alloy quenched at its solidification point, but much more minute. Quenched on solidification, the alloy presents a remarkable appearance. It has a cell-like structure, the centre of each cell being dark and the walls light coloured; many of the cells appear to have a white nucleus. In parts of the field dark lines are seen, short as yet, but the beginning of a new structure. The whole presents the appearance of the solidification of two liquids which will not mix together.

If the alloy is quenched before the end of the first break, though after the solidification of the whole mass, a new structure is seen. The cells remain with their white walls; but the background has become split up into dark and light, like a mesh. Between one system of mesh and the adjoining there is an irregular dark band.

Quenched below break 1, at 700° C. (1,292° F.), the cell structure disappears, and the whole field is covered with a "shot" structure, closely resembling the "schiller" structure of bronzite in appearance. The alloy is crystalline, each crystal having a different orientation and appearance. If the alloy is cast on an iron plate the "shot" structure reaches its full development; but it is absent in an ingot of the alloy, in which a coarse banded structure takes its place.

When the alloy is quenched below break 2, at 610° C. (1,130° F.), the "shot" structure has almost entirely disappeared, and the alloy has the appearance of being slowly cooled, but with the difference that no eutectic-like structure can be discovered.

68·3 per cent. Cu, 31·7 per cent. Sn. Two breaks, 745° and 580° C. (1,373° and 1,076° F.)

When this alloy was quenched liquid, the author failed to obtain any structure on etching. Quenched on solidification, the alloy shows a remarkable structure. Black grains and dendrites can be seen without the aid of a lens, and under the microscope dark grains are seen set in a lighter matrix; under a higher power the majority of these dendrites are seen to pass into the lighter matrix quite imperceptibly, the whole being covered by a fine needle-like structure. The whole appearance is one of incomplete metamorphosis. When quenched much below break 1, the dark grains disappear and the alloy appears homogeneous. If the alloy be cast on an iron plate, the structure is almost the same as that of the ingot, but is much smaller and more distinctly granular. The borders of each grain are rectilinear and sharply defined; orientation is marked.

73 per cent. Cu, 27 per cent. Sn. Four breaks 770°, 745°, 510°, 470° C. (1,418°, 1,373°, 950°, 878° F.)

Quenched liquid, the structure is but imperfectly seen, and appears to consist of dark grains in a matrix. The alloy appears the same when quenched on solidification or between the first and second breaks at 760° C. (1,400° F.). It consists of dark dendrites and skeleton crystals in a lighter matrix. These dendrites have dark borders. The skeleton crystals appear to be the same as those whose pseudomorphs are seen on the surfaces of the slowly-cooled alloys.

Quenching at 650° C. (1,202° F.), below break 2, gives the alloy a mottled appearance. The dendrites have quite disappeared, and white irregular roundish patches are seen in the dark background. Throughout the whole mass minute rosette-like crystals of whitish colour are scattered. They are doubtless stunted forms of those which appear when the alloy is quenched at 500° C. (932° F.), below break 3. In this alloy large grains are seen with polygonal boundaries of a white material. The grains themselves are made up of white radiating crystals and bunches of granules. The matrix is black, but under high powers no eutectic can be made out. But for the latter peculiarity, the alloy is identical with the furnace-cooled specimen. The cast specimen shows traces of the skeleton crystals which form on the surface of the slowly-cooled alloys.

76 per cent. Cu, 24 per cent. Sn.

As the last two distinct breaks of this alloy are the same as those of the next alloy, quenching was performed only at solidification. Small yellow dendrites and skeleton crystals are seen set in a matrix which is markedly composite, the two constituents being dark minute rounded grains in a lighter matrix. No trace can be seen of the thick skeleton crystals found on the surface of the slowly-cooled alloy. Strange to say these appear quite distinctly when the furnace-cooled specimen is re-heated to about 750° C. (1,382° F.) and quenched. If re-heated to a pasty consistency and then quenched, the alloy seems to consist of these thick skeletons, in the midst of which appear the small yellow grains and dendrites.

80 per cent. Cu, 20 per cent. Sn. Three breaks, 870°, 790°, 500° C. (1,600°, 1,454°, 932° F.)

When quenched from the liquid state, small yellow composite grains are seen in the dark structureless matrix. Quenching below break 1 produces large skeleton crystals composed of many-shaped yellow grains. No marked structure can be seen in the ground-mass. When quenched below break 2, at 750° C. (1,382° F.), the yellow grains have grown considerably, and the ground-mass has a coarse fibrous appearance, which is quite distinct from that of the furnace-cooled alloy. Again, when the alloy is etched so as to make the dendrites of copper appear a blackish-red, they appear to be surrounded by a white envelope. In places the matrix appears quite amorphous.

From the above evidence it is clear that branch *e* of the cooling curve, Fig. 1, denotes a change of structure, and this is a change in the solid. In the 66 per cent. Cu alloy the first break is that of solidification; the second is that of separation into the light and dark constituents; whilst the third is that of the formation of the small eutectic out of a part of the light constituent. With regard to the 73 per cent. Cu alloy, it is doubtful whether the first break means the solidification of the whole or of only a part. If the latter, the second break *d* must mean the solidification of the remainder. It seems more probably to be one of change in the solid. The upper break of 76 per cent. Cu and 80 per cent. Cu alloys is that of the solidification of the copper grains and dendrites. The second means the solidification of the ground-mass (branch *c*). The horizontal part of *e* is the eutectic break; and therefore the third and doubtful break in the 76 per cent. alloy must mean the separation of the bright white constituent from the ground-mass, which is distinctly shown in Fig. 85, Plate 199.

Considering the many and distinctly different structures produced in the series by quenching at different temperatures, and by re-heating and then quenching, it is quite evident that the changes which take place during the cooling of an alloy of copper and tin, especially in the neighbourhood of the second eutectic alloy, are even more numerous than those of the Carbon-Irons.*

Preparation of the Alloys.—1. *Slowly cooled.*—Each alloy weighed 200 grains. In the alloys containing up to 1 per cent. of copper, the tin was first melted under potassium cyanide in a small clay crucible, and copper was then added in the form of foil (electro-copper containing 99·8 per cent. Cu). It was found that the copper quickly dissolved in the tin. A large amount of the alloy containing 40 per cent. Cu and 60 per cent. Sn was carefully prepared by melting the copper first and then adding the tin. From this the alloys between 1 and 40 per cent. Cu were prepared by adding the requisite amount of tin. In each case the alloy was melted first, under potassium cyanide and carbonate, and the tin was added afterwards. In the alloys containing above 40 per cent. Cu the copper was melted and then the tin added. The crucible was well shaken in order to mix the contents thoroughly, and was then taken out of the fire and allowed to cool slowly on the top of the furnace in the open air. When cool the cyanide was washed away, and the button of alloy taken out.

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* Roberts-Austen. Molecular Unrest in Solids: Philosophical Society of Glasgow, 1900.

2. *Cast.*—When the alloys were cast, a thick iron mould was used cold. The alloy was melted as before, and when liquid was poured into the mould. The resulting ingot was about $\frac{1}{4}$ inch thick. When the alloy contained only a small percentage of copper, the greater portion of the cyanide was first poured off, because it was found that it retarded the cooling when poured into the mould along with the alloy.

3. *Furnace-cooled.*—Each alloy weighed about 800 grains, and was prepared as before. When the alloy was thoroughly melted, the crucible and contents were placed in a hot larger crucible containing charcoal powder; this outer crucible was already in place in a hot fire. The lid was put on the crucible, and the fire was then banked up with ashes; the dampers were closed, and all draught stopped. In 24 to 36 hours the fire had died out, and the crucible and contents were taken out, Fig. 110 (page 1248). In this way extremely slow cooling was obtained, the effect of oxidation was minimised, and the size of the crystals and structure was in general increased, in some cases by ten diameters.

Cutting, grinding, and polishing.—The alloy was cut with a saw, and a smooth surface was obtained by drawing it downwards over the face of a smooth-cut file held vertically, the tang pointing downwards.* The next stage of the operation consisted in rubbing the specimen on sheets of emery paper varying from 2 to 0000 in fineness. The papers from 0 to 0000 were moistened with paraffin oil. If the papers are attached to a quickly revolving wheel, a great amount of time and labour is saved. On each paper the rubbing was stopped immediately the marks of the previous paper had been obliterated. In some cases the rougher grades of emery paper could be omitted, and the surface ground down upon a flat Turkey-stone, using paraffin oil to moisten it. The specimen was next polished on broadcloth with rouge moistened with oil, using practically no pressure. In the alloys containing only a small percentage of copper, it was found that the best way to obtain a good polish and to remove the scratches due to the emery, and at the same time to prevent the spreading of the softer metal, was to use diamontine powder and oil, and to polish with the finger.

Etching.—The specimens were next placed in alcohol and thoroughly soaked, then washed and placed in a solution containing 1 per cent. nitric acid in water. In about 30 seconds the acid brings out the structure. The specimens were then taken out, washed, dipped in 1 per cent. hydrochloric acid to remove oxide of tin, again washed, soaked in alcohol, and dried. If the structure was not fully developed, the specimen was again etched. When the alloys contain a large percentage of copper, considerably stronger acid must be used for etching.

Isolation of Crystals in the 1 *to* 40 *per cent. Cu alloys.*—The alloy was placed in an ordinary gold-parting tube filled with 10 per cent. nitric acid, and allowed to stand till quite disintegrated. The acid was poured off and the residue washed. 10 per cent. hydrochloric acid was used to remove the oxide of tin remaining; but great difficulty was experienced in getting rid of the last traces. The crystals were then washed and dried. In most of those furnace-cooled alloys of which the eutectic formed a considerable part, a dark powder was obtained together with the crystals. Under the microscope the powder was seen to consist of minute bright plates with irregular borders. Their colour was the same as of the bright crystals, and it is probable that they formed one of the constituents of the eutectic.

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* Stead. Journal of the Society of Chemical Industry, March 1897, page 200.

Details and Description of Figures.—Plate 189 shows the recorder of the pyrometer, front and back view, which explain themselves. The whole in place and in working order is seen in Fig. 5.

Fig. 1 (page 1214) shows the freezing-point curves of the copper-tin series by Dr. A. Stansfield, published in the Fourth Report of Alloys Research Committee, 1897, Plate 10.

Fig. 2 (page 1216) is the composition curve of crystals isolated from alloys containing from 1 to 40 per cent. Cu; it is constructed by plotting the relation of the percentage of copper in the crystals to that in the whole alloy. The change in direction at 8 per cent. Cu is due to the introduction of the new constituent at that point. The curve can be only approximately right, owing to the great difficulty in isolating the crystals in a pure state.

Unless otherwise stated, the alloys have been slowly cooled on furnace top, and the magnification is 20 diameters, vertically illuminated (× 20 diams. *v*). The letters *f. c.* denote furnace-cooled; *o* = oblique illumination; *v* = vertical illumination.

0 to 1 per cent. Cu.—On the addition of even 0·1 per cent. of copper to tin, a new constituent surrounding the grains of tin can be distinguished. As the percentage of copper increases, the amount of enveloping material increases also; and the tin grains decrease in size and number, until at about 1 per cent. Cu they entirely disappear.

When these alloys are cast, the grains of tin are greatly reduced in size. It appears also that the tin in crystallizing out retains some copper, or else that the eutectic contains more copper than when slowly cooled, because the proportion of grains of tin to eutectic in those alloys which have been cast seems greater than in those slowly cooled. Again, with 1 per cent. Cu the cast alloy shows no signs of the bright crystals, which are clearly seen when the alloy is cooled in the furnace.

Fig. 6, Plate 190, shows an alloy containing 0·25 per cent. of Cu, in which the grains of tin are seen enveloped in a dark constituent, the eutectic.

Fig. 7 is a 0·5 per cent. Cu alloy. The grains are much smaller than before, and are surrounded by a considerable amount of eutectic.

Fig. 8 is the same cast in an iron mould. The grains are very small, and the relative proportion of eutectic is greatly diminished.

Fig. 9. The copper has been increased to 0·75 per cent. The tin appears as dendrites and irregularly shaped grains. Most of the field is covered by the eutectic, in which the grains and dendrites of tin are seen to have crystallized. The dendrites have long axes with projecting grains, round, elliptical, and club-shaped.

Fig. 10 shows a curious structure often met with in 1 per cent. alloy.

Fig. 11 is the same deeply etched. The bright minute plates are probably those of the eutectic, which in places are abnormally large. It is possible that they may be the initial crystallization of the bright constituent which appears distinctly when the alloy is furnace-cooled.

Fig. 12 shows the 1 per cent. alloy *f. c.* The eutectic point has been passed: that is to say, there is more copper present than necessary to form the first eutectic of tin and copper. In the ground-mass occur small bright acicular crystals, whose section is rhombic. In many cases they are hollow, and are often terminated by long pyramids. They polish extremely well, are steel-coloured by ordinary light, but appear white by vertical illumination. They are hard but not very brittle, and easily polish in relief. Etching with dilute acid does not affect them, and on exposure they oxidise only slightly to a pale yellowish colour. Their width varies from 1–150th to 1–300th of an inch. They contain about 34 per cent. Cu. As they are but few in number, the eutectic in the 1 per cent. alloy must contain almost 1 per cent. of copper. A vertical section of the alloy was weighed, dissolved in 10 per cent. nitric acid, the oxide of tin got rid of by weak hydrochloric acid, and the resultant crystals weighed; but not a trace of dark powder was obtained with them. Taking their composition as 34 per cent. Cu, 66 per cent. Sn, we can find the weight of copper contained in them, and hence the weight and percentage of copper in the eutectic. This proves to be 0·9 per cent.

Fig. 13 is the upper part of a 1 per cent. alloy *f. c.* near the outside.

Fig. 14, Plate 191, shows crystals isolated from a 1 per cent. alloy. They are the largest obtained as yet.

When the 1 per cent. alloy is cast the mass appears to be homogeneous.

1 to 8 per cent. Cu.—As the copper is increased from 1 to 8 per cent. the bright hollow rhombic crystals become more and more numerous. At first they occur isolated; then they tend to form groups, which appear in section as three and six-rayed stars, composed of single lines of crystals. As the percentage of copper increases, these stars become more complex, each ray being composed of more than one line of crystals. The crystals become more ragged and less clearly defined, due for the most part to parallel growth.

Casting produces a network of very fine crystallites, which tend to set along definite directions, forming skeleton crystals. These become more and more interfering as the percentage of copper approaches 8 per cent., and the individual crystallites become larger. On separation by 10 per cent. nitric acid, a black powder is left behind after the oxide of tin has been removed. Under the microscope this appears to be composed of fine plates, which are evidently the crystallites.

Cooling in the furnace greatly increases the size of the bright crystals, and diminishes their number proportionately; but does not alter their other characters.

With 1·3 per cent. Cu, bright needle-shaped crystals are seen, and under the microscope the field appears very similar to Fig. 12.

Fig. 15, Plate 191, represents a 2·6 per cent. Cu alloy. The crystals have greatly increased in number, and tend to form groups, many of which in section show an axis with three arms equally inclined; in the 5 per cent. alloy, Fig. 16, the groups are clearly seen as characteristic six-rayed stars. The crystals in section are horse-shoe shaped, being generally hollow. Their rhombic shape is seen in Fig. 17, showing a 5 per cent. alloy furnace-cooled, in which the crystals happen to be cut across their long axis.

Figs. 18, 19 show several crystals isolated from a 5 per cent. alloy *f. c.*; they are similar to those from the 1 per cent. alloy *f. c.*, and like them tend to parallel growth.

Fig. 20 is a 5 per cent. alloy cast. The whole mass is composed of a fine network of minute crystallites. Six-rayed stars are seen, and each ray forms an axis of crystallization, from which bands of fine crystallites proceed till they meet and are continuous with those from the next ray or axis. The whole network or web is a true skeleton crystal, of which the crystallites all tend to set in definite directions. In other parts of the field figures of rhomboid form are seen, composed of bands of crystallites parallel to the boundaries.

Fig. 21 shows an 8 per cent. Cu alloy. The crystals spread across the whole field, and are more irregular in shape than in the 5 per cent. alloy. Six-rayed stars are frequent, but each ray is composed of more than one line of crystals.

Fig. 22, Plate 192, shows the same when cast. The crystallites are much larger and thicker than in the 5 per cent. alloy, Fig. 20. There is an evident tendency to crystallize along certain directions, as before; but as the crystals occur closely together, it is only in places that definite figures are seen.

9 to 40 per cent. Cu.—With 9 per cent. of copper a new constituent crystallizes out in forms similar in section to the crystals in the 1 to 8 per cent. alloys, but differing from them in never occurring hollow. On oxidation it becomes very dark, and is easily distinguished from the other two constituents of the alloy. In form it is plate-like, and good specimens show a tendency to

crystallize as basal crystals, probably rhombic; around it crystallizes out the bright constituent characteristic of the 1 to 8 per cent. alloys, either as a rough envelope of fairly uniform thickness, or as projecting crystals. In the slowly-cooled alloys containing about 9 per cent. Cu, the difference between the constituents of the crystals can be seen only under high powers, when it is easily distinguished by its colour; but when between 20 and 30 per cent. Cu is reached, oxidation shows a darker centre or core to the crystals. The probable reason why the new constituent cannot be easily made out in the lower alloys is because it does not readily oxidise. As the copper in the alloy increases, the copper in the new constituent increases, its freezing-point rises, and it becomes proportionately more oxidizable. The series is best studied when furnace-cooled, as the new constituent can then readily be seen forming the core of composite crystals.

As the copper approaches 40 per cent., the plate-like crystals are grouped together in parallel bunches, until at 40 per cent. Cu they are very thick and cover more than half the field. In the eutectic between them the small bright hollow crystals are seen.

Casting masks the composite character of the crystals, if in the lower percentage it does not destroy it; for under 20 per cent. Cu the crystals cannot be resolved into two components under high powers. On dissolving out the eutectic by dilute nitric acid (1 in 10), a black powder is left behind in the alloys near 9 per cent. Cu, and in those near 40 per cent. a spongy brittle framework of crystals. The black powder consists of fine plates, which go to build up the skeleton crystals, as in the cast alloys containing from 1 to 8 per cent. of copper.

Fig. 23, Plate 192, shows a 10 per cent. Cu alloy. Under high powers the central core of many of the bright crystals is seen to be of a darker character, whilst from its side grow out crystals of the bright constituent.

Fig. 24 shows an isolated crystal from the 10 per cent. *f. c.* alloy. It shows the method of growing in parallel groups, forming in this way a large skeleton crystal.

Fig. 25 shows a 10 per cent. Cu alloy, *f. c.* The characteristic horse-shoe or hollow crystals are abundant.

Fig. 26 represents a rough section of the same alloy, which was exposed to the atmosphere for some time; the composite nature of these larger crystals is clearly seen.

Fig. 27 shows the same alloy cast. There is a distinct tendency to form skeleton crystals, but no composite crystals could be discovered in the alloy. It is very similar to the 8 per cent. cast alloy, Fig. 22. If however the alloy be cast when pasty, amongst the network of fine crystals can be seen composite crystals. The 9 per cent. alloy behaves in a similar manner.

Fig. 28 shows a 20 per cent. alloy. The crystals have increased in number and size; most are composite.

Fig. 29 shows the same alloy, obliquely illuminated; the specimen is taken from the centre of the mass, where the crystals are larger. Several of the horse-shoe type are seen in the eutectic.

Fig. 30, Plate 193, shows a 20 per cent. Cu alloy *f. c.* Composite crystals are seen on the right; while on the left are seen two crystals of the bright constituent, cut very obliquely across their long axes, thereby giving a drawn-out appearance to what would have been horse-shoe shaped, had they been cut more nearly to the normal to their long axes.

Figs. 31 and 32 represent two crystals isolated from a 20 per cent. *f. c.* alloy, which show distinctly the difference in colour, texture, and mode of crystallization of the two components of each crystal.

Fig. 33 shows a rough section of a 20 per cent. *f. c.* alloy, which has been exposed to the atmosphere along with Fig. 26. The crystals have been cut normal to their basal plane.

Fig. 34 represents a 20 per cent. alloy cast, and shows a network of long lath-like crystals which are no longer composed of crystallites. Under high powers they are seen to be composite. There is a general tendency to crystallize in groups, which continues throughout this part of the series.

Fig. 35 shows a 30 per cent. Cu alloy. The composite crystals have grown much larger, and are beginning to interfere with one another.

Fig. 36. When cast the appearance is similar, but on a much smaller scale. This hair-like network produces a very tough alloy. The crystals are all composite.

Fig. 37 shows the surface of the cast 33 per cent. Cu alloy. In cooling, the eutectic has contracted and left the crystals standing above the surface of the ingot.

Fig. 38, Plate 194, contains 40 per cent. Cu. The plate-like composite crystals have become broad, due to multiple growth, and occupy most of the field. In the eutectic between them, the finer prismatic crystals are seen in section in the usual horse-shoe form.

Fig. 39. When cast, but little of the eutectic can be seen. The crystals are long, thin, and give the mass a highly fibrous appearance. The tendency to form groups is marked.

Fig. 40. The surface of the cast alloy shows several points from which crystallization has started, and the shrinking of the eutectic in solidifying gives a characteristic appearance.

41 to 61·7 per cent. Cu.—The difference between the alloy containing 40 per cent. and that containing 41 per cent. Cu is very marked. The crystals in the latter are small and lath-shaped, arranged more or less in groups, and separated from one another by eutectic. They are composite as before, but the white constituent surrounds the dark as an envelope of uniform thickness, not as a rough incrustation. No single prismatic crystals of the white constituent have been seen in the eutectic. The alloy is brittle, and apt to break in cutting; the brittleness increases with the percentage of copper. With each addition of copper the groups of crystals become more and more compact, and the amount of eutectic diminishes until at 56 per cent. Cu it disappears altogether.* The bright constituent of the crystals grows smaller and smaller; at 56 per cent. Cu it takes the place of the eutectic, and forms the ground-mass in which the constituent containing the higher percentage of copper has solidified. When 61·7 per cent. Cu is reached, the bright constituent disappears, and we have a

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* Stead. Journal of the Society of Chemical Industry, June 1897, page 506.

homogeneous mass of $Sn\ Cu_3$, probably a definite compound. It is crystalline, each crystal or grain having an orientation different from its neighbour's. It seems to have a cleavage.

Casting seems to harden and toughen these alloys, as it makes the groups of crystals more compact, and tends in the lower percentages to make the crystals themselves fibrous. The surface structure is often very beautiful, and is seen in places to be composed of long fibrous crystals, together with others of a curved and contorted nature. In the higher percentages of the group, casting produces the massive crystalline structure characteristic of cast lead, tin, and zinc, &c. Above 50 per cent. the eutectic cannot be distinguished, and the alloys become brittle, and hard to cut. It is almost impossible to illuminate numerous pittings of the prepared surfaces.

When the alloys are furnace-cooled, their appearance differs but little from that of the ordinary alloy. The structure appears to be simply magnified, although it seems that the re-arrangement of the constituent which first solidifies does not take place till the total copper exceeds 41 per cent.

Seeing that these alloys up to about 56 per cent. Cu show four breaks in their cooling curves, it would naturally be expected to find four different constituents in each. Three only however can be distinguished. Quenching below the first and second breaks gives a difference in structure only. As in the alloys containing 61·7 per cent. Cu and upwards, branch *e* of the complete freezing-point curve corresponds with a re-arrangement in the solid; and as the difference between the 40 and 41 per cent. Cu alloys is one of structure only, we may assume that the second retardation in the cooling curve of these alloys is one of re-arrangement also.

Fig. 41, Plate 194, shows the 41 per cent. alloy, and consists of bright lath-like crystals surrounded by the eutectic. There is a distinct tendency to form groups, which in

Fig. 42, the 43 per cent. alloy, is still more marked.

Fig. 43 shows the same alloy cast. The crystals have a highly fibrous appearance, and the groups are shorter and more compact.

Fig. 44 shows the cast surface of the 43 per cent. alloy; there is a characteristic fern-like structure quite distinct from that of Fig. 40.

Fig. 45 shows the 46 per cent. Cu alloy. The groups have become much more compact, and merge into one another.

Fig. 46, Plate 195, shows the 50 per cent. alloy, polished slightly in relief. There is a further merging of the crystals into one another. Each group of crystals has its own orientation.

Fig. 47 shows the same alloy quenched below the first break in Fig. 1 (page 1214). It has a distinct granular appearance.

Fig. 48 shows the same quenched below break 2. The crystals have formed groups, as in the slowly-cooled alloy, Fig. 46, each group having a distinct orientation.

Fig. 49 shows the 56 per cent. Cu alloy, in which etching has been carried far enough to distinguish the two constituents. The eutectic is missing.

Fig. 50 shows the 60 per cent. Cu alloy *f. c.* Oxidation shows the dark constituent surrounded by a matrix of the bright one.

Fig. 51 shows the alloy containing 61·5 per cent. Cu *f. c.* This alloy is extremely brittle, but cuts well with a file. Its structure is large, being composed of crystals with irregular boundaries. There seems to be a cleavage.

61·7 to 68·2 per cent. Cu, $SnCu_3$ to $SnCu_4$.—The changes which take place between these two points can be observed only when the alloys are very slowly cooled. Each addition of copper to $SnCu_3$ brings in more and more of the bright constituent $SnCu_4$. Branch *e* of the cooling curve determines the structures of the alloys to a great degree. Quenching and casting produce structures totally new. The alloys set as a whole at the first break, and tend to re-arrange themselves subsequently in the solid.

Fig. 52, Plate 195, contains 62·5 per cent. Cu *f. c.* Irregular patches and grains of the dark $SnCu_3$ are seen surrounded by the bright $SnCu_4$.

Fig. 53 is the 63 per cent. Cu alloy, and shows an increase in the bright constituent.

Fig. 54, Plate 196, shows the 64 per cent. Cu alloy. There is a large increase in the bright Sn Cu_4. The dark constituent in places has lengthened out, sometimes forming long irregular bands dividing one area from another.

Fig. 55 represents the 65 per cent. Cu alloy. More than half the field is covered by the bright constituent. Sinuous bands of the dark have increased, whilst its granular structure has gone. Under higher powers a new structure is noticed in places in the white Sn Cu_4.

Fig. 56 shows this structure. It closely resembles a eutectic, and accounts for the lowest break in the cooling curve, namely the horizontal branch of *e* running from 65 to 68 per cent. Cu in Fig. 1 (page 1214).

Fig. 57 shows the 66 per cent. Cu alloy *f. c.* There is a further increase of the bright constituent, the dark being still in the form of elongated masses and bands. The eutectic-like structure is still present in places, in the midst of the bright constituent.

Fig. 58 shows the same alloy slowly cooled. It would seem that the dark constituent has been endeavouring to arrange itself in definite directions. The eutectic is conspicuous.

Fig. 59 shows the 66 per cent. Cu alloy, quenched on break 1. There is a cell-like structure, with light coloured walls or boundaries. The background is composed of a network of a definite character.

Fig. 60 is the same quenched on solidification. The cell-like structure is marked, and the dark lines of the background are almost wanting. Hence it may be assumed that on solidification the structure is that of Fig. 60, but it immediately commences to change, if not quenched at that instant.

Fig. 61 is the same, quenched below break 1. The cell-like structure of Fig. 60 has gone, and this new structure has taken its place.

Fig. 62, Plate 197, is the same, quenched below break 2. It has all the characteristics of the slowly-cooled alloy, Fig. 58, Plate 196, excepting the eutectic. So that break 2 must mean the re-arrangement into the two constituents, and break 3 the eutectic.

Fig. 63 is the 66 per cent. Cu alloy cast on an iron plate. It is similar to Fig. 61, and shows that the re-arrangement into light and dark constituents has been forced.

Fig. 64 is the same alloy cast as an ingot. Large areas are seen of black and white. In each area the black lenticles are arranged in a definite direction. There is no sign of a eutectic.

Fig. 65 shows the 68·3 per cent. Cu alloy *f. c.* It is composed almost entirely of bright grains, more or less elongated. The alloy has been rather deeply etched to show the form of the grains. It has a conchoidal fracture, and is extremely brittle.

Fig. 66 is the same alloy cast on an iron plate. It consists of polygonal grains similar to those seen in a pure metal. Each grain has definite boundaries, more or less straight, with distinct orientation. Again, each grain seems to be made up of minute cubes, giving it a black and white appearance when deeply etched, like that of pure iron. This resemblance to a metal is further marked when viewed under a magnification of some 2,000 diameters, when each grain is seen to be built up of a network of grains arranged in a definite manner, generally as a skeleton with two axes at right angles. The skeleton-like appearance of the secondary grains is due to the etching material, which has eaten deeper into their edges compared with their centres.

Fig. 67 represents the ingot of the same alloy. The primary grains are larger than in Fig. 66, but are built up of secondary grains or cubes as before. The alloy thus has every appearance of a compound.

Fig. 68 is the same alloy quenched on solidification, that is, during break 1. Irregular rounded grains or patches of a dark material occur in a lighter matrix. Under a higher magnification, Fig. 69, the dark matrix is seen to pass gradually into the light material, which is composed of fine short needles. The whole represents a transition which becomes complete at the second break.

68·28 to 74·5 per cent. Cu.—Immediately the copper is increased above 68·2 per cent., the second eutectic makes its appearance, enveloping the polygonal grains of $Sn\ Cu_4$. As the copper increases, the grains split up into veins and dendrites, which attain their full development in the neighbourhood of 72 per cent. As the total copper increases, the eutectic increases also, the veins of $Sn\ Cu_4$ gradually disappear, and finally the dendrites go, leaving the mass entirely made up of eutectic about 75 per cent. Cu. The alloys are best studied when furnace-cooled. Above about 71 per cent. Cu their surfaces are seen to consist of a network of dendrites or skeleton crystals, resembling those seen on the surface of a pure metal. This network continues right up to the copper end of the series. It was soon noticed that the internal structure of the alloys from 70 to 75 per cent. Cu showed no trace of dendrites; and accordingly the surfaces of several were rubbed down and polished, so as to lay bare their internal structure. In each it was the same as that of the centre of the alloy, which shows that the dendrites have split up and re-arranged themselves after solidification, and all that remains of them is this surface structure.* Quenching proves that the second and third main breaks (branch *e*) of these alloys mean re-arrangement into dendrites and eutectic; but just below break 1 there occurs a small break which is difficult to explain. It leaves the outer curve at 68·3 per cent. Cu, and runs horizontally to about 74 per cent. It seems probable that it takes place in the solid also, because the appearance is identical of the alloys quenched on solidification, and of those quenched between solidification and break 1.

Casting masks the structure of the alloys in the lower percentages, and nothing but bright veins in a darker groundmass can be seen under low powers. Under higher powers however the usual character can be seen. About 73 per cent. Cu, traces of the skeleton crystals seen on the surface of the furnace-cooled alloys can be observed in the centre of the ingot. They appear dark and structureless, as if they had not been able to resolve themselves into their two constituents.

Re-heating the furnace-cooled alloys to 700° C. (1,292° F.) and quenching them produces a structure similar to that of the cast alloys. Annealing after such a treatment restores the original structure.

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* Heycock and Neville, Proceedings, Royal Society 1901, vol. lxviii, page 171.

Fig. 70, Plate 198, shows the 72 per cent. Cu alloy *f. c.* Large areas are seen with bright boundaries, and composed of bright dendrites and rounded grains set in a dark matrix, which is the eutectic.

Fig. 71 is the 73 per cent. Cu alloy *f. c.* The bright boundaries are getting smaller and the dendrites fewer.

Fig. 72 is the surface of the same, cut and polished. Etching has brought out the structure of the surface crystallization, and shows it to be complex.

Fig. 73 is the 73 per cent. slowly-cooled × 53 diams. *v.*

Fig. 74 is the same alloy quenched on solidification; the dark grains of a rounded or irregular shape occur in a light matrix. Their relation to the first and to the minor break has not been settled as yet.

Fig. 75 is the same alloy quenched at 650° C., below these two breaks but above those of branch *c.* It shows a mottled appearance of light and dark, the whole being studded with minute white grains. The action commenced in the upper breaks is incomplete, and the white dendrites have been forced out as white grains.

Fig. 76 shows the same alloy quenched at 500° C. below the second main break. The structure is the same as in the furnace-cooled alloy. The ground-mass however, under ordinary powers, does not show a eutectic structure. Hence the second main break means the separation out of the veins and dendrites, and the last means that of the eutectic from the ground-mass.

Fig. 77 shows the 73 per cent. alloy cast as an ingot. It is a view of the upper part of the centre of a vertical section. The darker parts are the remains of the surface crystals of a slowly-cooled alloy. Under higher powers the structure of the remainder is the same as that of a slowly-cooled alloy.

Fig. 78, Plate 199, represents the furnace-cooled alloy, Fig. 71, which has been re-heated to about 700° C., quenched, and annealed. The annealing has not been carried far enough, leaving the specimen in a transition state between a slowly-cooled alloy and one cast or quenched.

Fig. 79 shows the 74 per cent. Cu alloy *f. c.* The whole mass consists of eutectic, which crystallizes out in large grains or crystals with irregular boundaries, but with distinct orientation. The alloy is rather brittle, but cuts and polishes well. The bright veins have entirely disappeared, but here and there patches of the dendrites remain. These latter are few in number however, and show that the eutectic is almost reached.

Fig. 80 shows such a patch in the 74 per cent. alloy *f. c.* The general form of these dendrites is a three-rayed star. Many stars go to each patch, but in any one patch all the stars are set alike, and so a regular mesh is formed.

75 to 100 per cent. Cu.—When 76 per cent. Cu is present, two new constituents make their appearance, and the alloy assumes a yellow tint. It loses its brittleness. In section are found yellow grains, surrounded by a bright white border, set in the second eutectic, in which small bright white grains also occur. Now this eutectic of the 76 per cent. alloy is much larger in character than that of the 74 per cent. Cu specimen : which may account for the fact that the eutectic break rises some 30° C. as it passes from 74 to 75 per cent., Fig. 1.

As the total copper is increased, the yellow grains increase, forming dendrites and skeleton crystals; the white borders and grains merge together, and the eutectic decreases till at about 90 per cent. it disappears. The yellow grains become darker and darker, containing less and less tin in solid solution, till they reach copper colour. The light borders diminish and disappear, leaving only copper dendrites behind at about 95 per cent. These dendrites vary in composition from centre to outside, and so the centre etches a darker colour. They darken with increase of copper till 100 per cent. is reached, when we have the characteristic structure and colour of pure copper.

When the alloys are furnace-cooled, the structure is much enlarged, and the nature of the alloys becomes clear. Casting, on the other hand, masks the character of the alloys, and tends to make the copper grains solidify, containing a considerable quantity of tin. In this way the eutectic can be made to disappear considerably below 90 per cent.

Quenching shows that the upper break corresponds with the solidification of the copper, and break 2 with the solidification of the ground-mass, which splits up into a eutectic when branch *e* is reached. The meaning of the small and almost vertical branch of *e* running upwards from 75 to 77 per cent. Cu, Fig. 1, is not quite certain, but it most probably indicates the separation of the white grains from the ground-mass, as seen typically in the 76 per cent. Cu alloy *f. c.*

Fig. 81, Plate 199, shows a 75 per cent. Cu *f. c.* cast surface. Large dendritic crystals are seen with distinct forms. On cutting and polishing this surface, Fig. 82, no sign of these crystals was seen, but the alloy appeared granular, each grain being surrounded by a border of harder matter which polished in relief. The difference is probably that in the softer parts the eutectic has separated out, and in the harder it has been unable to do so.

Fig. 83 is the same *f. c.* alloy re-heated to a pasty condition and quenched. The large crystalline structure formed on the surfaces of these alloys has been set up, but the quenching has prevented it from re-arranging itself.

Fig. 84 shows the 76 per cent. Cu alloy *f. c.*, in which yellow and white grains make their appearance for the first time.

Fig. 85 is the same × 53 diams. *v.* The three constituents, the large yellow grains of copper, the white grains and borders, and the eutectic, are easily distinguished.

Fig. 86, Plate 200, shows this alloy quenched at solidification. Small well-formed yellow dendrites occur in what appears to be a homogeneous matrix, which has been unable to arrange itself. It possesses however a minute cell-like structure.

Fig. 87 shows the 76 per cent. *f. c.* alloy re-heated to pasty and quenched. It resembles Fig. 83 in structure, but within the centre of each arm of the crystals small rounded grains can be seen.

Fig. 88 is an example of the surface structure of one of these alloys, the 77 per cent. Cu *f. c.*

Fig. 89 is the same, cut through the crystals, polished and etched. It shows distinctly that the crystals have re-arranged their internal structure, and under a slightly higher power the eutectic is recognised. That the dendrites of copper have formed first is not evident in this alloy, but in the higher percentages it becomes clear.

Fig. 90 shows the 77 per cent. alloy cut through the centre. It is composed of polygonal grains, and each has a definite structure.

Fig. 91 is the 80 per cent. Cu alloy slowly cooled, whilst

Fig. 92 shows the same alloy, which has taken a considerably longer time to solidify. The dark copper dendrites and grains have considerably increased in number and size, and the amount of eutectic has decreased proportionately.

Fig. 93 is the same alloy quenched when liquid. Small irregular grains of copper are seen in a dark matrix which appears to be structureless.

Fig. 94, Plate 201, is the same alloy quenched below break 1. Large dendrites and skeleton crystals of copper are seen in a structureless matrix.

Fig. 95 is the same quenched below break 2. In places the matrix is structureless, but in general it has the coarse fibrous structure of a eutectic.

Fig. 96 is the centre of the same, etched with hydrochloric acid, causing the copper dendrites to appear whitish in colour. It shows the fibrous appearance of the eutectic, as if its formation had been forced.

Fig. 97 is the surface of the 80 per cent. Cu alloy cut, &c.

Fig. 98 is the same, and shows that with this percentage of copper, the dendrites of copper have directed the formation of the surface skeletons. It is possible that the alloy may have set as a whole at the upper break, and that the dendrites of copper may have formed at break 2; but this hardly agrees with the fact that the period of break 1 increases in magnitude, whilst break 2 decreases.

Fig. 99 is the 80 per cent. Cu alloy cast, vertical section. It is very tough, cuts well, and polishes easily.

Fig. 100 is the same cast alloy annealed at about 750° C. It has here re-arranged itself markedly. The eutectic can now be seen and the copper dendrites have grown considerably. This seems to add weight to the view that break 2 corresponds with the separation of the copper. But this is not so. It proves however that the copper dendrites continue to grow *below* break 2, that is, in the solid.

Fig. 101 shows the 85 per cent. Cu alloy. The eutectic is becoming less, as the copper increases.

Fig. 102, Plate 202, is the same under a higher magnification. The specimen has been very slowly cooled.

Fig. 103 is the 90 per cent. Cu alloy.

Fig. 104 is the same cut through the surface.

Fig. 105 is the same very slowly cooled. No eutectic can be seen, only the copper skeletons with their white borders.

Fig. 106 shows a 95 per cent. Cu surface, and the characteristic structure of the alloys of about this percentage.

Fig. 107 is the 97·5 per cent. Cu alloy, and has the usual structure of copper that is not quite pure.

Fig. 108 represents the unalloyed top of a Cu alloy that has been chilled. It contains some 35 per cent. Sn, and 65 per cent. Cu. The structure is quite distinct from that of the ordinary 65 per cent. Cu alloy, Figs. 55 and 56, Plate 196.

Fig. 109 shows an alloy made by pouring molten tin into molten copper, and allowing them to diffuse in cooling. The whole range of alloys from 70 per cent. to over 80 per cent. Cu is here seen at once.

Fig. 110 (page 1248) shows the method of making the furnace-cooled alloys; it is a section through the two crucibles and their contents. The whole was placed in a fire, and when the alloy had melted, the fire was damped down with ashes, dampers were shut, and the whole allowed to cool slowly.

Figs. 111 to 118, Plate 203, show sections of the alloys 1 to 45 per cent. Cu. The difference of structure in Figs. 115 and 116 is due to the furnace-cooling of the latter. Fig. 117 has been very slowly cooled, and is intermediate between the two. The difference between Fig. 116 and Fig. 118 is also marked.

Since writing this Paper, the Report of the Committee, consisting of Mr. F. H. Neville, Mr. C. T. Heycock, and Mr. E. H. Griffiths, appointed by the British Association to investigate the nature of alloys, has been read at Glasgow. The work was directed towards the verification of Roozeboom's theory of solid solutions in its application to the Copper-Tin Alloys, and embraced the series between 61 per cent. and 100 per cent. Cu or from Sn Cu_3 to pure copper.

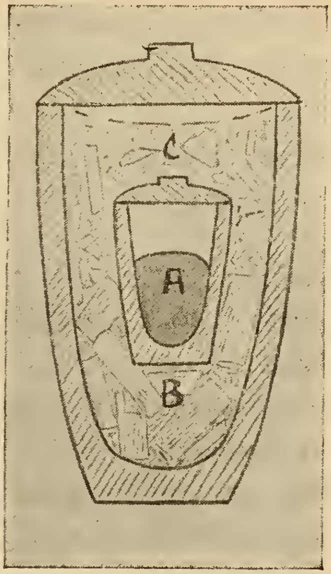

FIG. 110.

Section through Crucibles and contents for furnace-cooling.

A. Alloy.

B. Charcoal.

C. Charcoal and Charcoal Powder.

Their work is of a most extensive and elaborate character. It confirms for the most part the cooling-curve published in the Fourth Report of the Alloys Research Committee, and proves conclusively that the alloys, between the two points mentioned, re-arrange themselves after solidification, and that the branch *d* represents a change in the solid state.

The Paper is illustrated by Plates Nos. 189 to 203 and 4 Figs. in the letterpress.

APPENDIX.

Illumination of Surfaces for Examination.—The only satisfactory method, except for very low-power work, is by the use of reflectors. For magnification with a 1-inch objective the Sorby-Beck Reflector is the best. In Fig. 119, Plate 203, this reflector is shown attached to the 1-inch objective, the whole standing upon the reflector case. It is composed of two parts, the one consisting of the parabolic reflector of Beck, the other of the small Sorby mirror set at an angle of 45° with the vertical. When it is desired to obtain oblique illumination, the Sorby mirror is turned out of play. Light falling horizontally upon the parabolic mirror is reflected at all angles, except the vertical, upon the surface of the metal or alloy to be examined. If this surface be perfectly flat, the whole of the light will be reflected at an angle, and none will enter the microscope tube. Hence a flat surface will appear black. This oblique illumination is used to advantage when etching has been deep, or where there has been polishing in relief.

For vertical illumination the small mirror is swung into place, covering about half of the lower objective lens. Then the horizontal rays of light from the lamp or other means of illumination fall upon the mirror at 45°, are reflected vertically downwards on to the polished surface of the metal or alloy, and thence up the microscope tube. All flat surfaces will then appear bright. Excellent vertical illumination can be obtained by a very simple method, described by Mr. J. E. Stead in his Paper on Practical Metallography.* He says, "a piece of blackened cardboard, fixed behind the object in a vertical position, and a cover-glass placed over the object at an angle of 45°, gives excellent illumination. The card and cover-glass can be temporarily attached to the object-glass slip by plastic wax. It only takes a minute to arrange."

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* Proceedings, Cleveland Institution of Engineers, 26 Feb. 1900, page 97.

For high-power work, with objectives greater than 1 inch, the Beck illuminator is best. It is shown in Fig. 120, Plate 203, fitted to a $\frac{1}{4}$-inch objective and standing on its case. It is screwed into the microscope tube, and thus lies between the eye-piece and the objective. It consists of a short tube with a thin slip of glass fastened in the axis of the small milled-head, by which the glass can be adjusted to 45° with the axis of the microscope. The light enters the side of the reflector by the circular aperture, is reflected downwards through the objective on to the specimen, and thence back again through the objective, reflector and eye-piece, thus giving vertical illumination. Where electricity is available an arc-light is best for high-power work, but a Welsbach gas-burner gives a very good illumination. For low-power work, a Welsbach is all that is necessary. A bull's-eye condenser should be used to concentrate the beam of light upon the reflector.

A multiple nose-piece attached to the microscope saves much time in changing objectives. Fig. 121, Plate 203, shows a view of a camera and stand, together with a microscope fitted with a nose-piece carrying a 1-inch objective with the Sorby-Beck reflector, and a $\frac{1}{4}$-inch objective with a Beck reflector. This instrument is used in Professor Howe's Laboratory.

Discussion.

The President thought it desirable to point out exactly the relation in which the Paper, they had just heard, stood in regard to the work of the Alloys Research Committee. The series of experiments were carried out by the author under the direction of Sir William Roberts-Austen, and formed a complete series of examinations of tin and copper alloys, varying throughout from 1 per cent. tin with 99 per cent. copper to 99 per cent. tin with 1 per cent. copper. It was at first intended that the Paper should form one of the Appendices to the next Report of the Alloys Research Committee, but it was felt that it dealt with a complete investigation, not exactly connected with the main subject of that Report, and it was therefore thought better to bring it before the Institution as an independent Paper. The next Report of the Alloys Research Committee—which it was hoped would be brought before the Members early in the coming year—was a very important one, devoted chiefly to the effects of annealing steel, and it would afford ample scope for discussion in itself. Since Mr. Campbell's Paper had been prepared, the author had accepted an appointment at the Columbia University, New York, and he was therefore at present in the United States, but the Members had the advantage of the presence at the Meeting of Sir William Roberts-Austen, who would no doubt kindly reply to any points raised in the discussion.

Professor Sir William C. Roberts-Austen, K.C.B., Honorary Member, stated that Mr. Campbell's work on the microstructure of copper-tin alloys, especially as modified by quenching from a high temperature, was begun about two years ago in the laboratory of the Royal School of Mines. The results now published were submitted, in May last, to the Royal Commissioners of the 1851 Exhibition, from whom Mr. Campbell held a scholarship.

Turning to the original "cooling curves," which were published by the Alloys Research Committee of the Institution many years ago, Sir William claimed that the copper-tin curve was one of the earliest series of curves in which the complex changes that occurred in *solid* alloys had been revealed. The nature of the successive and more complete curves of the copper-tin alloys, which had followed the older one, was then shown. They all pointed to the fact that profound molecular changes occurred in solid alloys when they were subjected to suitable thermal treatment, and from the engineer's point of view such changes were of the utmost importance, as they affected the industrial use of the alloys. This was exactly what Mr. Campbell has attempted to study. His work was not as complete, either at the copper end of the series or at the tin end, as he had hoped to make it, the reason for this being that he had been called away to conduct, under Professor Howe, experimental investigations at the Columbia University, New York. As regards the important alloys known as "gun-metal" and as "white" or "bearing metals," Dr. Rose would kindly offer some supplementary details. With reference to the work of other experimenters, Heycock and Neville had published some beautiful photographs of copper-tin alloys (containing about 79 per cent. of copper), both when slowly and when rapidly cooled. They had also, in a quite recent communication to the Royal Society (page 1264), studied the copper-tin alloys from the point of view of the phase rule of Gibb. This had already been done by the speaker and by Professor Bakhuis-Roozeboom for the carbon-iron series, as expressed in the complicated cooling curve of this series, which was one of the most interesting pieces of work the Alloys Research Committee of the Institution had published. He concluded by saying that as soon as the molecular changes in alloys were thoroughly understood, greatly extended uses would be found for alloys generally; hence the industrial importance of the work of the Committee, which would, so far as the Institution was concerned, be brought to an end by the publication of their forthcoming Sixth Report, which would be a very complicated one dealing mainly with the annealing of steel. The work would then be continued in the National Physical Laboratory.

Dr. T. K. Rose said that although the Paper might at first sight appear to engineers to be somewhat too theoretical, nevertheless it was one of those pieces of work that was necessary to be done, to prepare the way for the application to the industries of our knowledge of alloys. For example, taking the well-known gun-metal containing about 90 per cent. of copper and 10 per cent. of tin, an answer was required to the question —“ What would happen when it cooled from a molten state to the ordinary temperature ? ” before it could be known what that metal was capable of. Solidification began in that alloy at about 1000° C. by the formation of crystals of nearly pure copper containing some tin, called by Messrs. Heycock and Neville the α crystals. As the temperature fell, those crystals continued to form, until at 790° C. (1454° F.) the mother liquor solidified, Fig. 1 (page 1214), forming what Messrs. Heycock and Neville called the β crystals. Below that temperature the alloy was entirely solid, but the α crystals went on growing at the expense of the β crystals, which continued to play the part of a mother liquor, although they were solid. Finally when the temperature had fallen to 500° C. (900° F.), the remainder of the β crystals split up into a “ eutectic,” consisting of a mixture of very small crystals of the α body and of what was probably Cu_4Sn. Now if at any of the intermediate temperatures, instead of being allowed to cool slowly, the mixture was quenched suddenly by being plunged into cold water, then the various bodies that existed at that particular temperature were, as it were, stereotyped and prevented from altering by the rapidity of the cooling. Widely different alloys were produced in this way, although they were all of the same composition. Mr. Campbell had determined the constituents of these alloys by microscopic examination, and it remained to determine their tenacity, their hardness, and their physical properties generally; for it was difficult to predict what would be the most useful alloys, until some such examination had taken place. In fact, the study of the effects of thermal treatment, already partly made in the case of steel, must be extended to other alloys.

The speaker then exhibited a number of slides, the first showing the 90 per cent. alloy which had been cast and then allowed to cool somewhat quickly. In this case the β body formed large meshes, but if the same alloy had been allowed to solidify slowly and had

(Dr. T. K. Rose.)

then been quenched, a totally different structure would have been obtained, consisting of small crystals of copper set in a dark matrix. This appeared to be of a very much higher tensile strength than the cast specimen. In both cases pure copper and pure tin were used in the preparation of the alloys. Other slides were shown of gun-metals containing 5 parts per thousand of oxygen and 1 per cent. of lead respectively, the thermal treatment of the specimens being identical with those mentioned above. All these specimens, however, tended to alter their structure very rapidly at ordinary temperatures, and care must be taken to remember this in examining the alloys. Outside the gun-metal series, interest in the copper-tin series centred chiefly in the anti-friction alloys, such as the "white metals" which contained from 80 to 90 per cent. of tin, 5 to 10 per cent. of copper, and usually 10 to 15 per cent. of antimony. The chief point about the metals, which were useful for bearing, was that they had hard grains set in a plastic matrix. In the case of the white metals the hard grains consisted generally of what used to be considered to be crystals of $SnCu_3$, but which were more probably CuSn. The crystals were in the shape of long needles, sometimes forming star-like aggregates, some of which might be seen in the illustrations to the Paper, Figs. 16 and 21, Plate 191. These hard crystals had a very low coefficient of friction, and supported the load. They were embedded in a plastic mass which gradually yielded to pressure, and consequently could shape itself to an axle or a shaft. Figs. 122 and 123, Plate 204, which were due to M. Charpy, were illustrations of one of the alloys showing the star-like crystals and cubical crystals consisting of a compound of antimony and tin. The alloy was used for railway-car axles in France, and contained 83 per cent. of tin, 6 per cent. of copper, and 11 per cent. of antimony. Fig. 122 showed the structure produced by simply polishing it, and Fig. 123 showed that developed by etching with hydrochloric acid. Hard crystals of CuSn were seen in relief, the softer matrix having been worn away. By carefully examining Figs. 91 to 105, Plates 200–202, it would be seen that the value for anti-friction purposes of the alloys containing from 80 to 85 per cent. of copper and from 10 to 18 per cent. of tin, with from 0 to 2 per cent. zinc, could be explained in a similar manner.

Mr. F. H. Neville said that Mr. Heycock and himself had been very much interested in the Paper, because it showed that two sets of workers had been going over the same ground quite independently and simultaneously. Messrs. Heycock and Neville had been saturated with the subject for nearly two years, and it was particularly interesting to hear it put in another man's words as in the Paper. The author started, like Mr. Heycock and himself, from the very beautiful curve of the copper-tin alloys worked out by Sir William Roberts-Austen and Dr. Stansfield; consequently, there must of necessity be a certain amount of similarity between their treatment of the subject and that of Mr. Campbell. He himself wished to say that he never realised how beautiful the Roberts-Austen and Stansfield curve was, and how much detail it contained, until they began to work with it, and then they saw how good it was.

Wherever their experimental methods were comparable with those of Mr. Campbell, they seemed to have obtained the same results. They recognised in the photographs the author had shown the same phenomena that they had observed themselves, the same bodies, the CuSn which Mr. Heycock and himself had isolated, although not quite in a pure state, and the Cu_3Sn which they had obtained absolutely pure from alloys of very different percentage composition. He thought there could be no doubt about the existence of those bodies, and, as Dr. Rose had explained, the CuSn fulfilled a very important function in the anti-friction alloys rich in tin. Their experimental methods had been very similar to the author's. They had taken a number of small ingots of alloy, quenched them at different temperatures, thus stereotyping the structure existing at each temperature, and obtained photographs very similar to his. It appeared to them to be very difficult to get a general grasp of the nature of the alloys, or at all events so to arrange the results as to make them intelligible to others, and in that respect possibly they had deviated from Mr. Campbell, and probably with some advantage. For, although in their experimental work their method had been so similar to the author's, they had in addition taken advantage of the theory of Professor Bakhuis-

(Mr. F. H. Neville.)

Roozeboom concerning the manner in which complexes solidified when they formed solid solutions, and by means of that theory they were able to state the results in a form which, though still difficult, was perhaps a little easier to grasp.

One of the principal new features in their diagram, Fig. 136 (page 1264), could be explained by Fig. 1 (page 1214) of the Paper. In that figure the upper curve *a d b* was the freezing-point curve, the curve giving the temperature at which each alloy *began* to deposit solid crystals. Any vertical line represented an alloy of a particular percentage composition, and if they followed such a vertical line from the top to the bottom of the diagram, they were really watching the alloy cool. Above the freezing-point curve the alloy was wholly liquid; when its temperature fell to the freezing-point curve, it began to solidify, and there *must be* a temperature at which it became wholly solid. If this latter temperature could be marked on the diagram for every alloy, another curve would be obtained, which would be the curve not of incipient solidification but of complete solidification. It would be a curve which might be called the melting-point curve, for by taking the cold alloy and heating it, it would begin to melt when it reached that curve. By a method which was not very accurate, but which was free from gross error, they had succeeded in tracing the melting-point curve, or curve of complete solidification, and he thought that it would be found a valuable addition to the figure. In their diagram, Fig. 136 (page 1264), the upper curve was the freezing-point curve, and below it was the curve of solidification or the melting-point curve. Whenever the alloy was above a certain temperature, between the freezing-point curve and the curve of solidification, it was a mixture of solid and liquid, and if quenched in that region of temperature would give large combs or skeleton crystals of a copper-rich material. It was no use quenching an absolutely liquid alloy, and in that they differed from the author; it was necessary, as Dr. Rose had said, to *stereotype a structure*, and it should be quenched when there was some solid. If quenched *between the curves* large copper-rich skeleton crystals would be found embedded in a tin-rich molten substance, which was liquid at the moment of quenching. It was a curious feature of the solidification-curve that whenever it sloped, or was curved, the solidified alloy was a uniform mass of crystals which were themselves a solid solution. Hence all the bronzes with less than 10 per cent. of tin when quite solid were really uniform masses. He said they were uniform because they ought to be, but there was often a slender network of something else around the crystals due to imperfect transformation. From the point of view of persons who did not care for a half per cent., although mechanical engineers knew that a half per cent. was often a very important thing, these alloys were uniform, a uniform solid solution of tin and copper. On the other hand, whenever the solidification-curve was horizontal, as it was between 10 and 25 per cent. of tin, the solidified alloy was *essentially* a complex of two bodies, like a piece of conglomerate rock. He would not venture to attempt to explain the whole of the diagram, but wished to describe its purpose. All temperatures and compositions had been divided up into areas. By that means they were able to say that, if an alloy was in a particular area, it was made up of certain proximate constituents. The diagram really studied would enable anyone to read at a glance the condition that the alloy was in at any temperature. And, as both they and Mr. Campbell had shown, the changes in structure undergone by some of the alloys during cooling were very remarkable. Consider the alloy, a speculum metal, containing 30 per cent. of tin. Their diagram recorded the following facts about this alloy: that when it began to solidify at about 760° C. (1370° F.), the crystals which formed were solid solutions, richer in copper than the liquid; that it had wholly solidified at 700° C. (1260° F.), and that it was then a *uniform* solid solution. The diagram further showed that this uniformity in the solid alloy continued to exist until the temperature fell to 560° C. (1010° F.); but that at and below this temperature crystals of Cu_4Sn formed in the alloy, and that at ordinary temperatures the alloy was a conglomerate of Cu_4Sn and another material, which was much softer and richer in copper.

This example might suffice to indicate the aim of the diagram, which gave similar information concerning every alloy of the copper-tin series. [*See page* 1263.]

Mr. C. T. HEYCOCK confirmed what had been said by Mr. Neville, and thought it was specially interesting that two people, who had been working by different methods and in different ways, should arrive at the same result.

Mr. J. T. MILTON said that for some time past he had taken a great interest in the question of the microscopic structure of metals, and amongst other metals he had worked upon the copper-tin alloys. Of these he had confined his attention to the alloys which came under the notice of the practical engineer, namely, the so-called "gun metals" and the "white metals." He thought the members were exceedingly indebted to the Alloys Research Committee for the work they had done, especially with regard to the cooling curves. Those shown on the wall diagram* were to his mind most wonderful curves. Each of the lines showed certain physical conditions of a definite alloy, and enabled one to see what changes took place in the molecular structure of the metal. The breaks in the curves showed what might be called the latent heat of fluidification. Sir William Roberts-Austen, in one of the earlier Reports, had shown that in the cooling curve of pure gold the break was absolutely horizontal, and had pointed out that when the break departed from the horizontal line it was because the metal was impure. Whenever the break of one of the cooling curves was other than horizontal, he (the speaker) thought it would be found that the metal did not crystallise out with a uniform composition. It really confirmed what the author had said with regard to the first solidification which took place in gun-metals, namely, that the dendritic forms were not uniform throughout their structure, but contained more copper in their central portions. He thought the same thing happened with regard to the white crystals in the 8 per cent. and poorer alloys. Another important point to engineers, brought out by the Paper and by some of the earlier Reports, was the great difference in the mechanical properties of metals, resulting from different thermal treatments. The author had shown that, in what he called "cast" metal, but which the speaker would prefer to term "cast on chill," the grain was exceedingly small; but when the metal was slowly cooled, it was usually much larger. That happened with every alloy. If metals were cooled very slowly from their fluid condition, some parts of them crystallised out earlier than others, and segregated together into large grains. The effect of gravity then came in, and in some instances separated the different portions; and instead of getting a uniform casting, a casting was obtained in which the upper part contained the lighter portions and the lower part the heavier portions. That was very common with the white metals, and occurred to a marked extent in some of those which were best known. The speed of cooling alloys was another point which was important in connection with gun-metals. When the first solidification took place and the first or yellow grains separated out, the mass was like a solid sponge or network, with the more fluid portions interspersed throughout. Referring to the diagram, Fig. 1 (page 1214), it would be seen that at 1000° C., or a little below it, only the yellow grains were solid, and that during the time the metal was cooling down to about 800° C. (1450° F.), no further solidification took place. During this fall of temperature however, the metal was shrinking, and not only each individual grain but also the volume of the still liquid portion became smaller. The liquid part therefore had a tendency to settle down into the bottom of the mould, and the upper portion of the casting would remain spongy. From that point of view he thought the best and soundest castings were to be obtained, when the conditions of casting were such as to cause the temperature to fall as quickly as possible. He had never seen a piece of ordinary gun-metal casting that appeared to be sound under the microscope. Besides the vacuities caused by the shrinkage, he had always found spots which he had put down to oxide. He thought that they were due in some measure to the fact that copper when fluid, as was well known to all metallurgists, dissolved oxide of copper and maintained it in a fluid form. It was with a view of getting rid of this oxide of copper that the process of "poling" was introduced. He felt sure that the copper of the gun-metal in melting took up oxide, and while the copper and tin were fluid, the oxide also was fluid and

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* *Third Report*, 1895; Fig. 10, Plate 41.

(Mr. J. T. Milton.)

dissolved in them; when however the copper solidified out, some of the oxide of copper became extruded. He always found the little spots of oxide were practically coincident with the positions of the matrix or eutectic, or the more fluid portion of the gun-metal between the yellow grains, and did not occur in these grains themselves. With regard to the preparation of specimens of the softer metals, in cutting up soft metals containing hard portions it was necessary to be exceedingly cautious and very patient, otherwise the hard portions were dragged through the softer matrix, and a wrong sort of image obtained. After sawing the metals, it was well to first rough-file the specimens to remove any portion dragged by the saw, and then to smooth-file them, always keeping the files wet with water. Carborundum powder was very sharp and cut without much dragging, as did also diamontine.

Mr. Milton then exhibited some slides to illustrate the remarks he had made. These are represented in Plate 205. The magnification in all cases is 40 diameters. Fig. 128 shows the separation which takes place by the action of gravity in one of the well-known white metals, when slowly cooled. The small granular portion is of greater density than the parts which appear light in colour, and settles to the bottom.

Fig. 129 shows the influence of the rate of cooling upon the structure of an alloy containing 8·5 per cent. copper and 91·5 per cent. tin. The left-hand portion shows the structure when the metal is cast on chill, the right-hand when it is slowly cooled.

Figs. 130 to 134 show the structure of alloys of copper and tin containing 4, 2, 1, 0·5 and 0·25 per cent. copper respectively. In all these sections the SnCu can be distinctly seen, but in diminishing proportions.

Fig. 135 is a section of the tin used, rather more deeply etched than the other specimens. It shows the granular structure of the tin. In Fig. 134 the etching was also sufficiently prolonged to indicate the similar granular structure of the matrix.

It was with some diffidence that he ventured to differ from the author as to the structure of the alloys at the tin end of the series. From the experiments which he had made, he had come to the conclusion that the lower eutectic did not exist, and that the matrix of the lower alloys was either pure tin or more probably tin with a very small amount, less than 0·25 per cent., of copper in solid solution. In making a series of alloys with 4, 2, 1, 0·5 and 0·25 per cent. copper respectively, he had been able to observe distinctly free spots of SnCu in all of them, although of course in the lower grade alloys the proportion of this compound was small. The tin he had used in making these alloys had been kindly furnished for the purpose by Mr. J. Dewrance, and was the purest tin commercially obtainable, and was certainly free from copper. It would be noticed from the slides that the tin itself showed a granular appearance similar to the 0·5 and 0·25 per cent. alloys of the author, while the 0·25 per cent. alloy not only showed the presence of the SnCu he had referred to, but also showed a somewhat granular appearance of the matrix of tin. In this case the granular appearance was due to the etching being carried rather farther than was necessary to show up the CuSn portion of the structure.

The President expressed the indebtedness of the Institution to Mr. Merrett, who, in the absence of Mr. Campbell, had aided very materially in preparing the Paper for presentation. Without Mr. Merrett's assistance, there would have been very great difficulty in getting it ready for that meeting. The discussion, together with written communications, would be submitted to the author who would reply to them in due course.

Communications.

Mr. Bertram Blount, in sending four photo-micrographs of copper, wrote that these photographs, which had been prepared by Messrs. Stanger and Blount's chief assistant, Mr. S. Dickson, might serve to supplement the series given in the Paper, as they represented copper of ordinary commercial purity and also the metal almost chemically pure. The following is a description of them:—

(Mr. Bertram Blount.)

Fig. 124, Plate 204. The pure copper, according to the result of a most rigorous analysis, contains 99·961 per cent. of Cu, and was prepared electrolytically by the Elmore process. Its enlargement is 115 diameters, and at this amplification it has a fine close structure not definitely crystalline. It will be understood from its mode of preparation that this metal is in the condition in which it was deposited, and has not been fused.

Fig. 125. A second specimen is shown of the same metal fused and cooled in hydrogen. In this case the structure consists of crystals of pure copper so large, that even with the moderate amplification of 40 diameters a single crystal occupies almost the whole field. The junctions of the crystals are quite sharp, proving that no fusible alloy or eutectic is present, as indeed would be predicted from the purity of the metal.

Fig. 126. A contrast is afforded by the next specimen, which is of good fire-box copper containing 99·54 per cent. of Cu. This was cut direct from a fire-box plate in the condition in which it would be used. The structure is definitely crystalline, but it will be seen that there are numerous aggregations of matter other than copper, forming dots and bands. These doubtless represent fusible alloys of the impurities with some part of the copper itself. On account of the metal having being worked in the manufacture of the plate from the ingot, the structure is more deformed and confused than would be the case with a cast metal.

Fig. 127. A piece from the same sample was fused in hydrogen, and allowed to cool slowly. The photograph of this specimen is enlarged to 40 diameters, and displays the separation of the alloying material from the relatively pure copper much more conspicuously than does the worked metal. The systematic study of such commercial metals and the correlation of their structure, with the observations of their behaviour in practice, cannot fail to yield results of importance to the mechanical engineer.

Appendix to Messrs. Heycock and Neville's Remarks (page 1255).

Messrs. Heycock and Neville, in sending a description of their diagram of the copper-tin alloys, wrote that the curve diagram, Fig. 136 (page 1264), and photo-micrographs, Figs. 137–139, Plate 206, were reproduced by permission of the Royal Society.*

The diagram, Fig. 136, aims at stating the nature of every alloy of the copper-tin series, not only at ordinary temperatures, but at all temperatures. Temperature is measured vertically, and is expressed in degrees Centigrade by the vertical scales at each end of the diagram. The percentage of tin in the alloy is measured from left to right, and is given by the two scales at the top of the diagram. The upper scale of unequal divisions gives the percentage by *weight of tin*, the lower scale, of equal divisions, corresponding to the vertical lines ruled on the diagram gives the *atomic percentage* of tin in the alloy. This scale practically gives the chemical formula of the alloy; thus the number 20 indicates that the alloy contains 20 atomic weights of tin out of every 100 atomic weights present, so that its formula is $Cu_{80}Sn_{20}$, or more simply, Cu_4Sn.

It is evident that a point on the diagram stands for a definite alloy at a definite temperature, while a vertical line defines the composition of an alloy, but does not state its temperature.

The curve ABLCDEFGHIK is the freezing-point curve, called by Professor Bakhuis-Roozeboom "the liquidus," because when the temperature of an alloy lies above this line, the alloy is wholly liquid.

The line $AblcdefE_2E_3H'H''IK'$ is the "solidus," so called, because when the temperature of an alloy lies below the solidus, the alloy should be wholly solid. The "solidus" might be called the "melting-point curve," for if a cold alloy is gradually warmed, it will begin to melt when its temperature is that of a point on the solidus. Whenever an alloy is in the region of temperature between the solidus and the liquidus, it is partly solid and partly liquid, consisting of skeleton crystals immersed in a mother liquid which is richer in tin than the crystals. These skeleton crystals can be detected by chilling an alloy, when its temperature lies between the

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* Proceedings of the Royal Society 1901, vol. 69, page 322.

(Messrs. Heycock and Neville.)

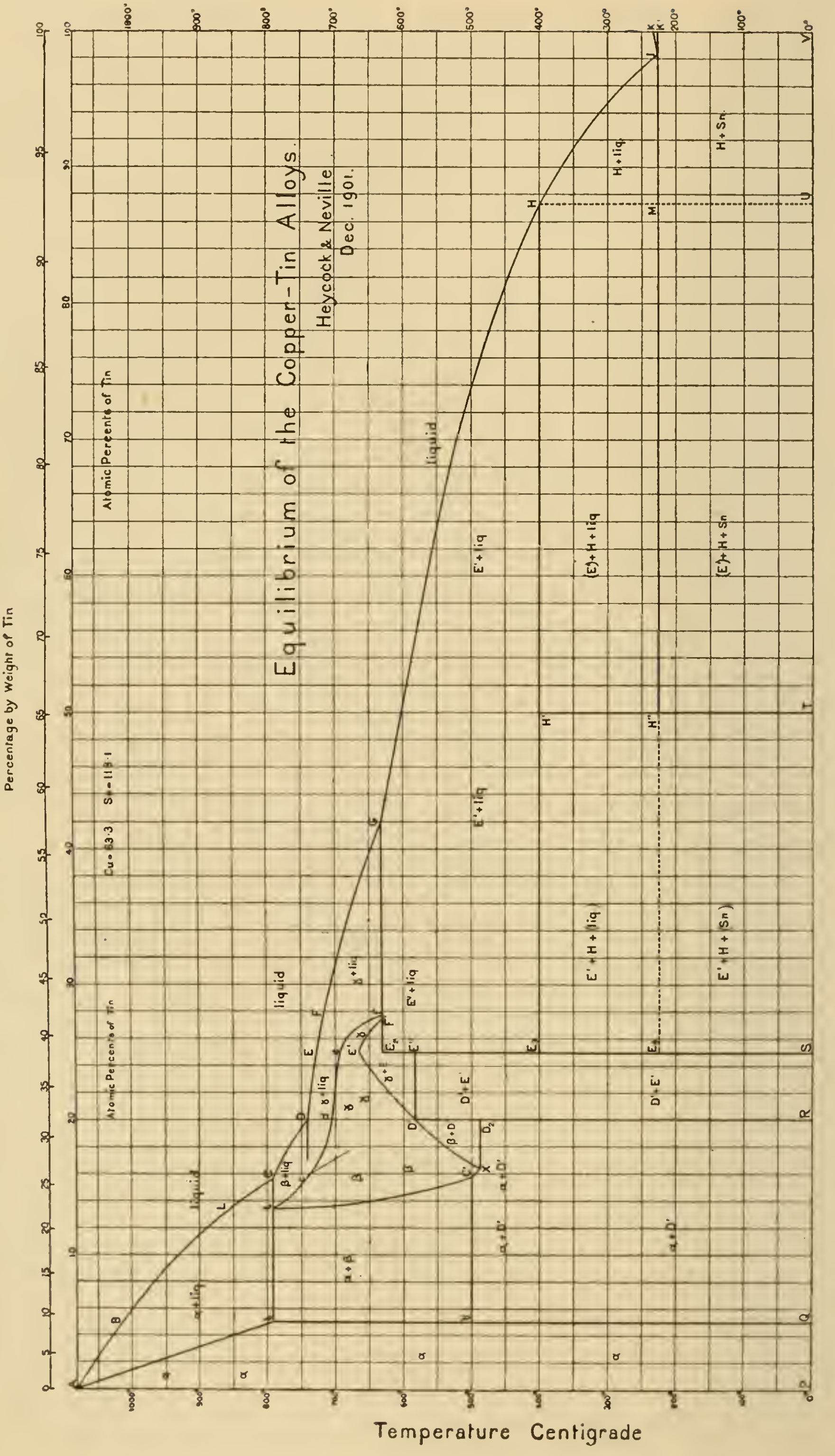


FIG. 136.—*Reproduced from Proceedings of the Royal Society.* (*Half size.*)

"solidus" and the "liquidus," but they do not always exist in slowly cooled alloys.

The remaining curve of the diagram, the curve lC′XD′E′F′, is Austen and Stansfield's curve of changes that take place in the solid alloys. These three curves, together with horizontal and vertical lines drawn through the intersections and singular points of the curves, enable one to divide the whole area into smaller compartments. Each of these compartments corresponds with a particular structure in the alloys, and so long as the point representing the alloy lies in a particular compartment the alloy possesses the structure peculiar to that compartment. Consider the bronze containing 7·5 per cent. of tin. While its indicating point lies in the compartment AbC, that is between the temperature 1,025° and 850° C. (1,880° and 1,560° F.), it will be a mixture of alpha crystals and a liquid richer in tin; while as soon as it comes into the compartment APQb, it should consist of a uniform mass of alpha crystals. No doubt the alloy if cast and cooled more or less rapidly would not be quite uniform (on account of imperfect transformations during cooling), but although Messrs. Heycock and Neville have not tried it, they believe that the cast alloy could be made uniform by rolling and annealing. On the other hand, the alloy with 20 per cent. of tin could never be made uniform, for when in the compartment bb′C′l it is a complex of crystals of two substances differing a good deal from each other, and when it falls to the compartment b′QR, although it has undergone further change, it is still a complex. No amount of annealing or rolling will make it other than a complex.

The alloy containing 30 per cent. of tin is one of a group that undergoes very remarkable changes of solidification. Three figures, Plate 206, are given which are reproduced from Messrs. Heycock and Neville's Paper in the Proceedings of the Royal Society (Vol. 68, Plate 3), which illustrate the changes.

Fig. 137 is of the internal structure in a sample chilled midway between the solidus and the liquidus. The large copper-rich skeleton crystals, dark in the photograph, are seen embedded in a tin-rich mother substance which was liquid at the moment of chilling. Fig. 138 is that of a sample of the alloy chilled below

(Messrs. Heycock and Neville.)

the solidus, but above the line D′E′. The alloy is now very uniform, consisting of grains of a solid solution; the grains are chemically all alike, but as they differ in orientation, it is possible by etching to distinguish them from one another. This state of chemical uniformity continues as the alloy cools, until the line D′E′ is passed, when the substance D′, or as they think, Cu_4Sn, crystallises out of the solid solution. Fig. 139 shows the white tin-rich bands and rosettes of this body. The same body can be seen in Mr. Campbell's Fig. 76, Plate 198. The three alloys, of which photographs are given, were not etched, but the pattern was developed by heat-oxidation. Instead of examining the changes which other alloys undergo as they cool, the various substances, or *phases* which exist in the chilled or the slowly cooled alloys, will be briefly considered.

The substance alpha is not a definite chemical compound, but is a solid solution of tin and copper, which varies in composition from pure copper to copper with rather less than 10 per cent. of tin; but all the alpha crystals are alike in form. There are very good examples of skeleton crystals of alpha in Figs. 92 and 94 of Mr. Campbell's Paper. In Fig. 92 the alpha skeletons are dark, and in Fig. 94 they are light, but this is due to differences in the orientation of the grains; and the fact that in Fig. 92 the lines of crystal make angles of 60° with each other, while in Fig. 94 they make angles of 90°, is due to the same cause.

The substances β and γ.—These, also, are solid solutions of copper and tin, which appear to differ from each other in crystalline form. There are no β crystals containing less than about 22 per cent. by weight of tin, and the γ crystal richest in tin contains about 42 per cent. of that metal. Mr. Campbell's Paper does not contain a good example of these crystals, but the dark skeletons in Messrs. Heycock and Neville's first figure of the quenched alloy containing 30 per cent. of tin are β or γ crystals. Neither β nor γ is ever found in a slowly cooled alloy.

The substance D′.—They believe, and so does Mr. Campbell, that this body is the chemical compound Cu_4Sn. It is remarkable for the peculiarity that it never crystallises from the liquid, but only begins to form when the solid alloys have cooled considerably below their temperature of complete solidification. The white rosettes and bands of their third figure of the 30 per cent. alloy consist of this body, and it can be seen, though not very well, in Mr. Campbell's Fig. 76, Plate 198.

The body E′.—This crystallises in plates, which seen edgewise often look like bars. The white bars in Mr. Campbell's Figs. 35, 38 and 40 consist of E′. They have isolated the plates of E′ from a number of different alloys, and in several cases found them to be the pure compound Cu_3Sn, but it is possible that sometimes the plates of E′ contain more tin dissolved in solid solution in the Cu_3Sn.

The substance H.—This occurs as a margin bordering the crystals of E′ in all slowly cooled alloys between 39 and 93 per cent. of tin. The effect is clearly seen in Mr. Campbell's Fig. 26, Plate 192. In the alloys containing less than 7 per cent. and more than 2 per cent. of copper, the H crystals occur without a core of E′, but their occasional hollow shape suggests that, when the alloy began to solidify, small nuclei of E′ formed which were redissolved. Mr. Campbell's Figs. 17, 21 and 25 show this H very well. H is the hard body in the copper-tin alloys which are used as anti-friction metals. Their own analyses, those of Mr. Campbell and of previous workers, all point to the conclusion that pure H is the compound CuSn, but they are not aware that anyone has separated crystals which on analysis proved to be quite pure CuSn.

It will be noticed that in some of the compartments the presence of three substances is indicated, but that the symbol of one of the three is placed in brackets. This is done to show that the bracketed substance is an intruder, whose presence is due to the imperfect completion of reactions taking place in a solid.

It might be thought that only the lower compartments of the diagram, which deal with the condition of the alloy at ordinary temperatures, could be of use to mechanical engineers; but Messrs. Heycock and Neville venture to differ from this view, as they believe that the upper part of the figure will be found to throw light on the probable consequences of such operations as rolling, chilling, and annealing.

The above is by no means a complete account of the information conveyed by the diagram, but it is hoped that it may suffice to make it intelligible and useful in connection with Mr. Campbell's Paper.

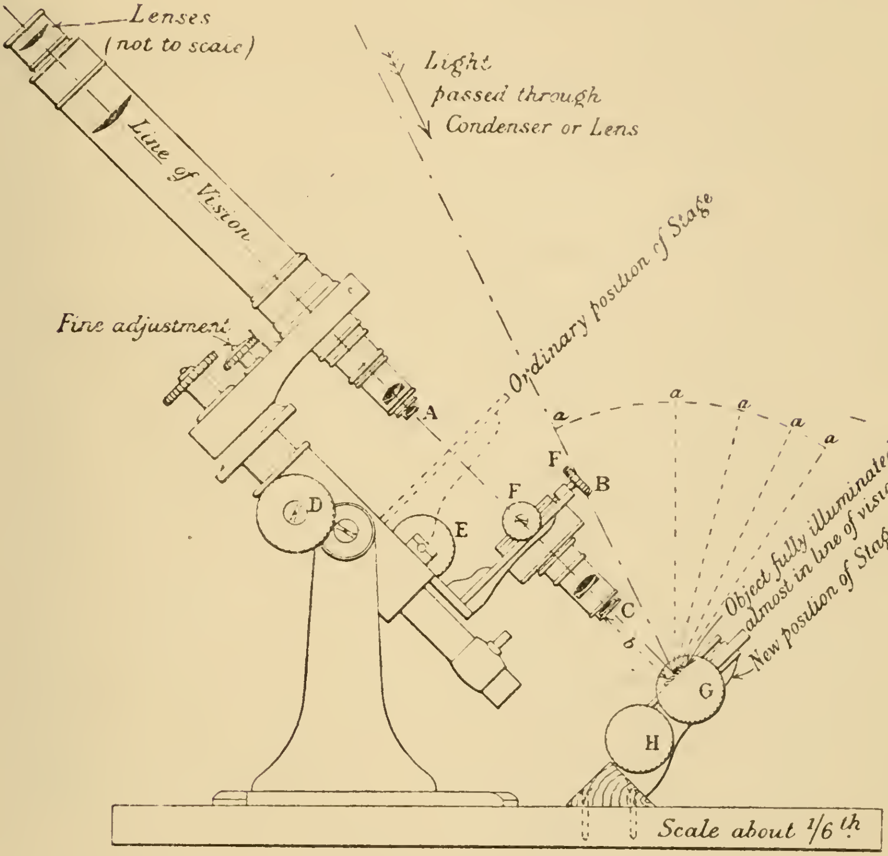
The authors wish to add that although they have complete confidence in the general accuracy of the diagram, yet it must be borne in mind that the shape of the solidus has as yet only been determined by approximate methods, and that further work will possibly somewhat alter the shape (but not the general character) of this curve, as well as the position of the point *b*.

Mr. David Joy sent a sketch, Fig. 140, showing an arrangement of a microscope which he found it necessary to make some years ago, when examining steel forging fractures at Barrow-in-Furness. It was for use with opaque objects—such as in slicings of granite to get the carbonic acid globules visible—that he wanted room under the objective to get in a flood of direct condensed light. Of course in using the usual high power of objectives like a ¼-inch, there was no room at all to get light between the object and the object glass, so he employed a low-power 3-inch objective next to the object, and this gave plenty of room to get an almost vertical ray of light. This objective was carried on the sub-stage usually employed for illuminators, having both centralizing screws and focus adjustments. Then he again magnified the image so obtained by a ⅓-inch objective mounted in the usual place, so getting a sort of double compound arrangement, which answered perfectly. He mounted the usual object stage (taken from above) on a block of wood below, thus having the adjusting movements in both directions.

Mr. Campbell, in reply, wrote that when the work was started, an explanation of several of the branches of the freezing-point or cooling curve, Fig. 1 (page 1214), had not, to his knowledge, been satisfactorily given; and it was in striving to find this explanation that the author had been employed during the past two years. He was extremely

Fig. 140.

Arrangement for examining opaque objects (Joy).



A.—½-inch objective, being second magnifier, magnifying the image made by the first objective C.

B.—Sub-stage usually used to carry illuminators, now used to carry first objective of low power, allowing room for full illumination, say 3-inch focus.

C.—3-inch objective magnifying the fully illuminated object.

D.—Milled handle to focus tube with ½-inch objective.

E.—Milled handle to focus sub-stage with 3-inch objective.

F F.—Milled handle to centre stage.

G.—Milled handle to adjust object stage laterally.

H.—Milled handle to adjust object stage to and fro.

a a a a a.—Scope of external illumination.

b.—Clear space to get in light.

(Mr. Campbell.)

pleased to find that the main results had proved comparable with those of Messrs. Heycock and Neville, for whose work he had the greatest admiration. Their diagram, Fig. 136 (page 1264), which unfortunately he had not had an opportunity of seeing before his work had been submitted to the Institution, explained nearly all the points of difficulty he had met with.

Dr. Rose (page 1253) had very clearly explained what happened when the 90 per cent. copper and 10 per cent. tin alloy cooled down from the liquid state. The author was unaware of the fact that below 790° C. (1,450° F.) the crystals of copper (α crystals) went on growing at the expense of the ground-mass (β crystals) to any great extent. This view of the case explained Figs. 99 and 100, Plate 201. In Fig. 99 the 80 per cent. copper and 20 per cent. tin alloy was seen as it appeared when cast in a small cold iron ingot mould; the long fine dendrites of copper (α crystals) appeared in a lighter ground-mass, presumably β rich in α. On account of the rapid cooling, only a part of the copper had been able to separate out. The ground-mass had not been able to re-arrange itself. In Fig. 100 was seen the same alloy annealed at about 750° C. (1,350° F.). The crystals of copper (α) have grown considerably, at the expense of the ground-mass, which under a higher magnification was easily seen to be composed of the eutectic, this re-arrangement of the ground-mass into a eutectic taking place at 500° C. (900° F.).

With regard to the "white metals," so well worked out by Charpy, it was interesting to note that nearly all of them used for anti-friction purposes contained less copper than that required to form the complex crystals found in the alloys containing between 8 and 41 per cent. Cu of the copper-tin series, Figs. 31, 32, and 33, Plate 193. In other words, the crystals of the copper-tin compound generally had a composition between 34 and 44 per cent. Cu, Fig. 2 (page 1216).

In respect to what Mr. Milton said (page 1258) about the cooling of gun-metals—namely, that during the time the metal was cooling down from about 1,000° C. to about 800° C. (1,800° F. to 1,440° F.) no further solidification took place; the author was of opinion that this was not the case. He felt sure that Dr. Rose's explanation was the right one, that the crystals continued to form until the mother liquor solidified at 790° C. (1,454° F.). Referring to the lower eutectic, whose existence Mr. Milton doubted, most of the workers upon the alloys of copper and tin mentioned it definitely. Charpy, in his Paper on the "Microscopic Study of Metallic Alloys," * followed Le Chatelier's cooling curve, and placed the first eutectic at 3 per cent. Cu. He described it as very delicately laminated, and said: "Alloys containing from 0 to 3 per cent. Cu are very soft.... long dendrites may be detected, however, probably of tin, surrounded by a matrix, in which some very thin, hard crystalline trails (traînées) are discernible." These crystalline trails of Charpy's are the hard CuSn constituent of the eutectic. The author had recently repeated the work on the tin end of the series, and at 0·9 per cent. Cu in a furnace-cooled alloy found the whole mass to be laminar, exactly resembling the first eutectic alloy of the Sb-Cu series. Below 0·9 per cent. Cu, tin crystallised out as dendrites in a matrix composed of the alternate soft tin and hard plates or needles of SnCu. At 0·1 per cent. Cu this matrix was quite distinct, and when this alloy had been diluted with an equal weight of pure tin, it could still be discerned when very carefully treated. Mr. Bertram Blount's description (page 1262) of the appearance of pure copper in the condition of deposition was extremely interesting, since the author had recently examined some electro-copper 99·9 per cent. pure, prepared by the Nicholls Chemical Co. of Long Island. With ordinary etching, no structure of a crystalline character could be seen, but by using strong nitric acid, a coarsely crystalline structure was brought out in a most marked way. Figs. 141 and 142, Plate 206, showed this pure copper just as it came from the depositing tank; a section was cut and polished in the usual way. It was then dipped in strong nitric acid and quickly washed. The process of etching was repeated till the true crystalline structure of the metal, consisting of large polygonal crystals distinctly oriented, was clearly seen. Fig. 124, Plate 204, showed what were commonly known as mixed crystals; that is to say, cooling had not been prolonged sufficiently

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* "Metallographist," vol. i, page 194.

(Mr. Campbell.)

to allow diffusion to establish a complete equilibrium. Given sufficient time in cooling, the crystals in Fig. 124 would appear as uniform as those in Fig. 122.

In illustrating this Paper the original photographs had to be reduced, generally from 33 to 20 diameters, and consequently several were indistinct. This was specially the case in those alloys containing between 68 and 74 per cent. Cu.

In conclusion, he wished to express his gratitude to Sir William Roberts-Austen and to Mr. Merrett for their great kindness, not alone in seeing the Paper through the press, but also for many valuable suggestions offered during the progress of the work at South Kensington.

GRADUATES' ASSOCIATION.

THE MANUFACTURE OF TIN-PLATE.*

By Mr. W. H. TREGONING, *Graduate*, of London.

The oldest industry in this country is probably that connected with the production of Tin. In the earliest ages the prehistoric Briton dealt with the outside world in tin. But the real tin-plate industry is of much more recent date. The hub of this industry is in the coal-field of South Wales. In Glamorgan, Carmarthenshire, and Monmouthshire there are about 450 tin-plate mills capable of turning out between 13 and 14 million boxes, that is, about 700,000 tons of tin plates yearly. The early tin-plate mills were nearly all driven by water power, and this fact accounts for the establishment of many of the oldest mills beyond the limits of the coal-fields.

Up to the year 1891 South Wales practically made the tin plates of the world, exporting enormous quantities to America and to other parts of the world. But by far the largest customer was the United States of America. In 1891 the American market was closed to the British by the introduction of the McKinley Tariff Bill, which raised the duty on tin plates from 4*s.* 6*d.* per box to 9*s.* 9*d.* per box; and then the troubles of the trade began. A box of tin plates of the size and weight upon which this duty is levied is worth in the market about 13*s.*

After four years of the McKinley tariff, the Wilson tariff came into operation, the present duty in the United States of America on tin plates being 5*s.* 7*d.* per box. In addition to this duty, freight from South Wales to Philadelphia or New York works out at about 8*d.* per box, while to Chicago freight charges amount to about 1*s.* 4*d.* per box. Consequently the American buyer has to pay in Chicago, 19*s.* 11*d.* for that which can be obtained in London for 13*s.*; so perhaps it is not surprising that he prefers to make his own tin plates.

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* This Paper, read on 11th March 1901, has been selected by the Council for publication.

In the last ten years tin-plate manufacturers have had to look around for new markets, and have succeeded in getting together a fair trade with the Continent, Austria, Russia, Australia, and South America. The business of the tin-plate manufacturer is not to make saucepans, boxes, milk-cans, &c., but to produce the tin-plate from which these articles may be made by the stamper or tin-smith. In the early days when the plates were made of iron, there was but little stamping or spinning in comparison with what is done today. The introduction of steel, with its capacity for enduring great tensile strains, has multiplied the demand for tin plates many times. Owing to the low cost and rapidity with which cans and utensils can be turned out with stamping machinery, the old trade of the tin-smith is of very much less importance than in former times, when large quantities of plates were made up into what is known as "pieced" work.

The principal uses of the tin-plate are for all sorts of stamped or "pieced" ware, for decorated boxes, for the canning of fruit, meat, salmon, vegetables, condensed milk, butter, oils—especially petroleum. The oil district of South Russia and the Standard Oil Co. are the largest consumers in the world. A very important use, too, is that for roofing purposes. The plate is then made in the form of terne sheets, which are sheets coated with a mixture of tin and lead. The composition of terne is varied very much by different manufacturers. A good mixture is about 3 of lead to 1 of tin.

For roofing purposes plates are extensively used in the United States of America, in Russia, and in the Danube district. For the United States roofing plates are made in sizes 14 by 20 and 28 by 20 inches, for Russia 28 by 28 inches, and for the Danube 29 by 58 inches. These are first seamed together, so as to make long strips the length of the roof from top to bottom of the gable, the several strips of seamed sheets being fastened to the close boarding of the roof with nails in a very ingenious manner, so that no nail passes through the sheets; the long strips are then seamed together, making the whole compact and rain-proof. Such roofs are by no means unsightly, and if the sheets are heavily coated, there is no reason why terne roofs should not be used with advantage in this country. In addition to sending out goods in the form of tin and terne plates, the manufacturer has to supply large quantities of material in the form of black plate, that is, as steel or iron sheets in various states of finish according to their uses. Thus enamelled ware is made from black plate pickled and close annealed. Special black plate is also produced for fenders, trunks, fry pans, front forks and mud-guards of cycles, and countless other uses.

The principal raw materials of the tin-plate manufacturer are tin, imported from the Straits Settlements, and the tin-bar, a bar of Siemens or Bessemer steel of any convenient length, and from 7 to 9 inches wide, the weight per foot-run of the bar varying according to the size and gauge of the tin-plate to be manufactured from it. The author has called the tin-bar raw material, because it is the point from which tin-plate making proper begins. Some tin-plate works have their own steel works attached, but the majority of manufacturers are content to buy their bars in the open market, provided they can obtain them clean, and guaranteed to stand certain specified strains. In the early days of the industry common qualities were made of puddled iron, and were known as coke plates; the better qualities were made of charcoal iron and were called charcoal plates.

The manufacturer at that time made the sizes which suited him best, and the tin-smith had to cut his patterns and make his articles in such a way that the standard sizes could be used with least waste. The chief standard size was originally known as 1 C. (that is, one Common); this was a box of 225 sheets, measuring 14 by 10 inches, and weighing in all 1 cwt. To suit the requirements of consumers wanting plates of greater thickness, plates were made of the same size, but 25 per cent. thicker, that is, each box weighed 140 lbs., and was known as 1 X (that is, 1 Cross); the next stronger thickness was 1 XX, and was 21 lbs. heavier than 1 X, and so on up to eight or ten crosses. Each additional cross after the first denoted that the plates were 21 lbs. heavier than 1 X, which weighed 140 lbs., as in the Table below:—

	Inches.	Sheets.	Lbs.
1 C	14 by 10	225	112
1 X	,,	,,	140
1 XX	,,	,,	161
1 XXX	,,	,,	182

The second standard size of early days was what is known as Common Double (C.D.). In this case the sheets were 17 by 12½ inches, and 100 sheets weighed 98 lbs., and, as before, to denote thicker plates of this size, crosses (X) were added, XD being again 28 lbs. per box heavier than C D, and each additional X marking an increase in weight of 21 lbs. Thus:—

	Inches.	Sheets.	Lbs.
C D	17 by 12½	100	98
X D	,,	,,	126
XX D	,,	,,	147
XXX D	,,	,,	168

There was a third intermediate size, 15 by 11 inches, 200 sheets to the box, weighing 160 lbs., known as Common Small Doubles or Common Middles, but these are today practically obsolete; they are only called for by certain Government departments and railway companies.

The terms 1 C, 1 X, C D, X D, &c., still have a distinct commercial meaning and represent different substances, although in all cases the standard has been reduced about 4 per cent. from the weights which these originally signified, the width of the sheet being doubled, and the number of sheets per box being halved. Thus :—

	Inches.	Sheets.	Lbs.		Inches.	Sheets.	Lbs.
1 C	14 by 20	112	108	C D	17 by 25	50	94
1 X	,,	,,	136	X D	,,	,,	122
1 XX	,,	,,	157	XX D	,,	,,	143

The modern manufacturer, with his Continental trade as against the old American trade, has to work to many other sets of gauges. Thus he is prepared to make sheets :—

(1) To the tin-plate gauge as expressed by the signs 1C, 1X, CD, XD, &c.
(2) To the millimètre gauge.
(3) To so many thousandths of an inch thick.
(4) To weigh so many ounces per square foot.
(5) To weigh so many grammes per square mètre.
(6) To any other recognised gauge, such as the B.W.G., Board of Trade standard gauge, Stubs gauge, &c.

Further, he does not confine himself to plates 14 by 20 inches, but makes any size his mills will turn out. A mill suited to ordinary tin-plate work will not roll to advantage sheets larger than 24 inches by 50 inches, 22 inches by 58 inches, 20 inches by 60 inches. Large plates become a strain on either the men or machinery.

For larger sheets special mills with more furnace accommodation, thicker rolls, and more engine power are constructed.

Thus a 40-inch mill would roll sheets 34 inches by 70 inches, a 48-inch mill would roll sheets 40 inches by 80 inches or 36 inches by 120 inches.

In an ordinary tin mill the handiest sizes are found to be:—

22 inches by 44 inches; 21 inches by 46 inches; 20 inches by 48 inches; 18 inches by 54 inches; 17 inches by 56 inches; and the like, although there is no recognised standard.

The first consideration of the manufacturer on receiving an order is to get a satisfactory tin-bar. In ordering the tin-bar the most important factor, which governs the length and thickness of the finished plate, is the weight per foot-run of the bar. Thus in making plates 14 inches by 20 inches by 30 B.W. gauge, that is, by the tin-plate gauge 1C substance, the first question to be decided is in what way the plates shall be rolled. Thus they might be made any length or width which is divisible by 14 inches or 20 inches, and the thickness of the plate might be arrived at by rolling on eights, fours, doubles, or singles. That is to say, the article as passed from the mill may consist of eight sheets rolled tight together of the required length and width, of four or two sheets in the same condition or of the single sheet. In this case, to make a plate 14 inches by 20 inches by 30 gauge, the sheets will probably be made with least waste if rolled 20 inches by 56 inches, so that in the finished piece there are four widths of 14 inches by 20 inches; and the thickness of the plate will best be arrived at by finishing the piece on "eights," that is, the finished piece passed from the mill will consist of eight sheets 20 inches by 56 inches rolled tight together.

The tin mill consists of two pairs of rolls, known as the roughing and the finishing rolls. The bottom rolls are coupled direct to the main shaft of the engine, while the top rolls revolve on the bottom ones. The equipment of the tin mill also consists of two furnaces where the pieces of bar may be heated, doublers—shears and squeezers, and mill shears.

It is usual to have two, three, or four mills lined up and driven by one engine, the auxiliary machines, such as shears, squeezers, &c., for each mill being driven off the main shaft.

The rolls are of highly chilled cast-iron with an extremely hard surface, generally of about 19 inches diameter with 13-inch necks, and varying in length according to the work they have to do. Thus rolls 28 inches long will work sheets from 18 inches to 24 inches wide by any length, while 38-inch rolls will work sheets from 27 to 34 inches wide. The bottom roll of the mill is connected direct to the main shaft, but the top roll is free to move up and down between the standards of the mill. This roll is kept down to its work by means of steel screws and boxes fixed in the upper part of the standard. These screws are manipulated by the roller-man as he feeds his piece into the rolls; and the pressure on the rolls is so adjusted that the plate leaves the rolls accurate as regards length and consequently thickness.

The rolls must be kept with some care, and will require turning up about once a week, an operation which takes from two to four hours per mill. To effect this, a slow motion must be fitted to the mill, so that the speed of the rolls may be reduced for this operation.

The piece of bar cut to the required length is first heated to a dull red heat and then passed to the roller-man who puts it through the roughing rolls, the behinder, a lad standing behind the rolls, passing it back to the roller-man, who sends it through the rolls in the same way five or six times. It is then passed back to the furnace-man, and charged in the fire again. After reheating, the plate is rolled again in a similar manner—this time in the finishing rolls, and if of a very thick gauge, to be finished on singles, it will now be drawn to the required length and passed from the mill. But the plate at this stage is too thick for the majority of uses, and so requires doubling. This is the doubler's work. He folds the plate over and then puts it under a squeezer. This is simply a cast-iron plate, receiving its motion from the main shaft, which rises and falls from a fulcrum, and coming down on an iron table squeezes down the piece placed on the table, so as to flatten it where it has been doubled over. This is necessary to enable the doubled end to enter the rolls on the next rolling. The doubled piece then goes back to the furnace, after which it is again rolled, and if finished on doubles it is drawn to the required length on this rolling.

If finished on fours or eights the piece must be again doubled, but this time the doubler has to do more than double, he must also shear off what is known as "the curled end"; that is to say, the end at which the first, not the new, doubling was made, so as to give four free ends at the back of the plate as it goes between the rolls. It is then reheated and once more rolled, this time on fours. If finished on fours it is drawn to the required length, the pressure on the last two "licks," or passes through the rolls, being carefully adjusted by means of the screws. If the piece is to be finished on eights it must again be doubled and squeezed; once more the curled end must be sheared off, and then after reheating, it can be rolled out to the required length in the same way as before.

As finished from the rolls the piece will consist of one, two, four, or eight sheets rolled tightly together. It will be an inch or two longer and broader than required, and will have rough jagged edges. From the rolls the piece is passed to the shearer, who cuts it up to the finished size; or rather a trifle smaller than the final finished size to allow for the extension of the plate when passed through the cold rolls later on. From the shearer the piece passes to the opener's bench, where the plates are rapidly torn apart by the openers and loaded on trolleys for conveyance to the next process, the pickling machine.

These sheets are now in the form known as "hard from the mill," and for some purposes, such as shovel plates, are ready for use.

For certain purposes plates in this finish are carefully annealed, and are then ready for use in making galvanized buckets and other similar work. For other purposes the plates, as passed from the opener's bench, are cold-rolled and then annealed; such plates are used for trunk making. But for tin-plate making proper these sheets "hard from the mill" have to go through many more processes. In the course of rolling and cooling, the plates have become covered with an oxide which cannot be tinned, and so must be removed by pickling. The plates are therefore packed in gun-metal racks, and plunged into a bath of sulphuric acid, where they remain for about five minutes. The rack containing the plates is suspended in the acid from a cross-bar, which is raised by steam through a height of about 2 feet, when the steam is exhausted and the bar with the rack drops in the tank of acid to be raised again. In this way the plates are kept in constant motion in the acid. When removed from the acid, the plates are suspended in the same way in a similar bath of water. The effect of this pickling is that the acid has eaten its way under the oxide, which remains on the plates in the form of a greenish black slime. This slime is removed by annealing. After pickling, the plates are packed in the annealing pots and roasted in the annealing furnace, until the slime is removed. This takes about ten hours, after which the pots are taken out and allowed to cool slowly. The annealing pots before roasting are made air-tight by filling up any joints or cracks with sand. The plates are now in the form known as pickled and annealed black plate. They are of a silvery whiteness in the middle with discoloured edges; and in this form enormous quantities are exported for stamping and enamelling.

The plates coming from the annealing oven are considerably buckled, and further have a somewhat rough surface. This rough surface, which is so useful in enamelling work, would make a very poor plate if tinned in this state. Before tinning the plate must be polished, and to this end it is passed several times through the cold rolls. This cold-rolling polishes the plate satisfactorily, and of course lengthens it a trifle, but as the plate was sheared in the mill a trifle short of the required length it is now, on leaving the cold rolls, true to size. This cold-rolling has not only polished the plate, but it has hardened it very much and has made it brittle. Consequently the next process must be in the annealing furnace once more; there the plates are roasted until they have reached a dull red heat, they are then brought out and allowed to cool slowly. The plate as brought the second time from the annealing furnace is known as black plate p. cr. and ca., that is, pickled, cold rolled and close annealed ready for tinning.

But it is necessary that the plate should reach the tin pot absolutely clean, without dust or grease. To attain this end, the plates are once more pickled in very dilute sulphuric acid, and after being washed in water are passed to the tin house, where they are kept in water until used in the tin pot.

In the early days of tin-plate making the iron sheet was merely dipped in a bath of tin, and allowed to take up just as much or as little metal as it would.

Now, however, the coating of tin must be regulated with much greater nicety, and the manufacturer must know to within 2 ounces how much tin is used per cwt. of plates. The amount of tin varies up to about 10 lbs. per cwt. of plates. The tinning sett consists in its simplest form of a tin pot, or iron bath filled with molten tin, and a grease pot filled with palm oil and containing a tinning machine.

The tinning machine is an arrangement of steel rolls about 4 inches in diameter, revolving in an iron frame, whose function it is to squeeze from the plate all superfluous tin.

The pace at which these rolls revolve can be varied within certain limits, and the pressure exerted between the rolls is capable of adjustment by means of springs and screws, so that the amount of tin left on the plate can be regulated with considerable accuracy. The steel sheet is dipped into the molten tin, through a flux of chloride of zinc, and from the bath of tin it passes up through the rolls of the tinning machine which is working in the grease pot. On emerging from the rolls of the tinning machine, the plate is caught up in a claw and carried to a rack where it is allowed to stand for a moment for the tin to set, after which it is rubbed in fine bran to clear away all traces of oil. The plate only requires now to be dusted before being sent to the assorting room. On the assorting table the sheets are carefully picked over by experienced men, the defective sheets being packed separately from the perfect plates. The defective sheets are again picked over into waste, and waste-waste. In plates of common coke quality the primes run from 80 to 90 per cent., with 17 to 9 per cent. of wasters and 3 to 1 per cent. of waste-waste.

In the heavily tinned "best charcoal" plates the assorting is much finer ; plates are thrown wasters for much more trifling defects. In this quality primes run from 40 to 80 per cent. of the whole. In best plates wasters vary according to size, the smaller the sheets the higher the percentage of primes.

The defects to which plates are liable are:—Round corners, that is, plates not full to size ; ragged edges ; pinchers, that is, the steel has lapped over in rolling ; stripes and other untinned spots ; bad surface marks, and plates improperly pickled. Stripes and other untinned spots are the general defect due to the difficulty of obtaining clean steel and clean coal.

From the assorting room the plates are weighed and reckoned, and packed in elm or birch boxes ready for shipment.

MEMOIRS.

George Armstrong was born at Bewcastle, Cumberland, on 5th April 1822. He became district foreman at the Chester Station of the Great Western Railway, under his brother—Mr. Joseph Armstrong—who was afterwards promoted to be chief locomotive and carriage superintendent. In 1864 he was appointed locomotive and carriage superintendent of the Northern Division of the Great Western Railway, and he continued to hold that position until his retirement in 1897. His death took place suddenly at Wolverhampton from failure of the heart on 11th July 1901, at the age of seventy-nine. He became a Member of this Institution in 1866.

Graham Stewart Bruce was born in Leghorn, on 6th November 1854. He was educated at the German School in Leghorn, and at the Percy Street Academy, Newcastle-on-Tyne, which latter Institution was founded by his uncle, Dr. Bruce. From 1871 to 1876 he served his time with Messrs. R. and W. Hawthorn, of Newcastle-on-Tyne, and remained with them as draughtsman for some time afterwards. He was next employed on the designs for the Jarrow Works of the South Shields Gas Co., which included the construction of a mechanical stoker. His next engagements were in the running-shed department of the Lancashire and Yorkshire Railway at Newton Heath, and of the North Eastern Railway at Gateshead. In 1881 he joined the South Indian Railway as assistant locomotive and carriage superintendent at Negapatam, and was promoted to be deputy superintendent in 1891. This position he held until the time of his death, which took place at Negapatam on 28th September 1901, in his forty-seventh year. He was a keen volunteer, having belonged to the Artillery Volunteers while a resident in Newcastle. He was an officer in the South Indian Railway Volunteers from their formation, and at the time of his death was Commandant with the rank of Lieut.-Colonel. He received the Volunteer Decoration in 1900. He became a Member of this Institution in 1899.

George Clark was born in Sunderland on 14th June 1843. He served his time at his father's works on the River Wear, and then spent a few years at Messrs. Penn's Works on the Thames. Owing to his father's illness, he undertook at the age of twenty-one the sole management of the Works, which developed rapidly under his direction. He served for a time on the Town Council of Sunderland, and was a member of the Durham County Council for about six years. He was also on one of the Trade Conciliation Boards, and took a leading part in the Engineering Employers' Federation. He had been a Justice of the Peace for the County of Durham for some years. His health had been indifferent for some considerable time, consequently he spent the winter in Mentone, where his death took place on 4th March 1901, in his fifty-eighth year. He became a Member of this Institution in 1867.

William Wikeley Clayton was born in Leeds on 4th December 1848, and was educated at the Grammar School in that city. After serving his apprenticeship with Messrs. Hudswell, Clarke, and Co., Railway Foundry, Hunslet, he went into the drawing office for a period, and was then appointed works manager. He was subsequently taken into partnership with the surviving partner, Mr. John Clarke. On the death of the latter, he became sole proprietor, and, on the conversion of the firm into a limited company, he was appointed managing director. For some years he was a member of the Leeds Board of Guardians. Having caught a chill while on a journey, pneumonia supervened, and his death took place at his residence in Leeds on 26th October 1901, in his fifty-third year. He became a Member of this Institution in 1882; he was also a Member of the Institution of Civil Engineers, and of the Iron and Steel Institute.

William Lorenzo Collins was born at Reading on 19th August 1873. He was educated at Marlborough College and at Sir Edmund

Currie's Engineering College, Folkestone. From 1892 to 1897 he served an apprenticeship at Messrs. John Fowler and Co.'s Steam Plough Works, Leeds, in the mechanical and electrical shops. During that time he assisted in superintending the erection of the electric light works at Coventry, Blackpool, Reading, and the Great Northern Railway Station at King's Cross. In 1898 he became an assistant engineer to Mr. Robert Hammond, consulting engineer, of Westminster, and assisted in preparing lighting schemes for Gloucester, Rangoon, Leamington, and Canterbury. He had also superintended the erection of plant for the electric lighting of Bath and Newport. His death took place at Reading, on 15th January 1901, in his twenty-eighth year. He became an Associate Member of this Institution in 1899.

Edward Corry was born at Clonbrin, Kildare, Ireland, on 25th December 1812. After having been educated at Mr. Lovell Edgeworth's school, he went to London in 1840, and became manager to the late Mr. William Brydges Adams, of Fairfield Works, Bow. In 1850 he started in business on his own account in Old Broad Street, London, as commission agent and copper and iron merchant. Owing to the stoppage of the Aberdare Iron Works in 1875 he failed in business, but was able to resume again soon after, and he did not remain satisfied until all his liabilities, together with interest, had been paid up in full. Among his earliest contracts was that for Southend Pier; he had also much to do with the establishment of railways in Russia, South America, Spain, India, and Ireland. His death took place at St. Leonards-on-Sea on 12th January 1901, at the age of eighty-eight. He became a Member of this Institution in 1848.

Robert Alexander Forsyth was born in London on 20th September 1849. Having been educated at Greenwich Grammar School, he received his engineering training at the General Steam Navigation Company's Works, Deptford. For thirty years he had been an inspecting engineer for Sir A. M. Rendel and Co., and for the last twenty years he was engaged in South Wales and

Monmouthshire on work for foreign railways, chiefly the Indian State Railways. Prior to that time he was for two years with the firm of Van Kyk, at their works of the Société Anonyme de Gosselies, near Charleroi, Belgium, under Sir A. M. Rendel and Co. His death took place at his residence at Gold Tops, Newport, Mon., on 27th October 1901, at the age of fifty-two. He became a Member of this Institution in 1882.

John James King was born in Oldbury on 27th September 1863. Having been educated at Lodge Estate Academy, West Bromwich, he continued his scientific studies at the Birmingham School of Science and Art, and the Midland Institute. From 1877 to 1882 he was engaged in the fitting and turning shops of the Oldbury Railway Carriage and Wagon Co., and in the latter year entered the drawing office of the Midland Railway-Carriage and Wagon Co., where he remained until 1885, when he was placed in charge of the drawing and estimating departments until 1887. In December 1887 he entered the service of Mr. James Dickson, of St. Albans, and with whom he remained until 1891. During this period he was engaged on various works, namely, Louth and Mablethorpe Railway, Cheshunt Main Drainage, Clerkenwell Viaduct, Mumbles Sea Wall, &c. In 1891 he entered the Stanton Iron Works, near Nottingham, as designing and superintending engineer in the foundry department, where he had charge of the extensive alterations and additions to their buildings and plant. This position he held up to the time of his death, which took place at Ilkeston, Derbyshire, on 12th May 1901, in his thirty-eighth year. He became a Member of this Institution in 1899.

Joseph Slater Lewis was born at Helsby, Cheshire, on 4th June 1852. He was educated at a private school at Nantwich, and at the Mechanics' Institution, Manchester. From 1868 to 1872 he served his time with Mr. George Slater, land agent and surveyor, of Northwich, and on its termination he was engaged in the coal trade at Malpas for some years. In 1879 he commenced on his own account as an electrical engineer at Helsby; and in the next year invented a self-binding insulator which was widely adopted in Europe and the United States. After a visit to the latter country to dispose of his American rights, he returned to Helsby and commenced the manufacture of his insulator on a small scale, adding later on other branches of electrical work. Eventually this business together with an insulated wire factory in the neighbourhood, was incorporated as the Telegraph Manufacturing Co. During the earlier growth and development of this concern, he acted as managing director, himself taking the chief part in designing the buildings and plant. Relinquishing his connection with the company in 1889, he, after practising as an electrical engineer in Birmingham, became manager in 1892 of the works of Messrs. W. T. Goolden and Co., London, which later on was incorporated with Messrs. Easton and Anderson, of Erith. In 1894 he accepted an offer from Messrs. P. R. Jackson and Co., of the Salford Rolling Mills, Manchester, to equip and start a dynamo-making and electrical engineering department, and shortly afterwards was appointed general manager of the entire business. At the end of 1900 he transferred his services to the Brush Electrical Engineering Co., as works director, and continued in this capacity until his death. He was the inventor of several electrical devices, and was the author of the standard book on "The Commercial Organization of Factories." At one time he was a county councillor for Cheshire, and chairman of its Weights and Measures Committee. In addition to his connection with the Brush Electrical Engineering Co., he was a director of the Swansea Tramways Co., and of the Merthyr Electric Light and Traction Co. His death took place suddenly from an attack of apoplexy at his residence in Norwood, London, on 27th July 1901, at the age of forty-nine. He became a Member of this Institution in 1898; he was also an Associate Member of the Institution of Civil Engineers, a Member of the Institution of Electrical Engineers, of the Iron and Steel Institute, and a Fellow of the Royal Society of Edinburgh.

Charles O'Keefe Mackay was born in Edinburgh on 16th November 1845, and was educated at Edinburgh High School.

In 1862 he was articled to Mr. William Hurst, locomotive engineer to the North British Railway, at St. Margaret's Works in Edinburgh. After five years' apprenticeship he went as draughtsman to Messrs. Dübs and Co., of Glasgow, after which he assisted Mr. D. K. Clark in the inspection and valuation of the rolling stock of the Caledonian Railway. He subsequently joined the Lancashire and Yorkshire Railway Co. in 1868, Mr. William Hurst having in the meantime succeeded to the post of locomotive engineer to that company. He remained as Outdoor Locomotive Superintendent until the date of his decease, which took place at his residence in Horwich, on 29th May 1901, in his fifty-sixth year. During his thirty-three years of service there were many improvements in the rolling stock of the company with which he was prominently connected, the chief of these being the introduction of the vacuum automatic brake. He became a Member of this Institution in 1892.

Robert Macmillan Murdoch was born at Old Cumnock, Ayrshire, on 3rd March 1844, and was educated in his native town. He served an apprenticeship from 1861 to 1866 with Messrs. McCartney and Co., a local firm of engineers and millwrights. On its termination, he entered the works of Messrs. James Aitken and Co., Glasgow. Shortly afterwards he went to sea as engineer in a new steamer, and sailed in African waters for nearly two years, returning in 1868. In 1869 he entered the drawing office of Messrs. A. and W. Smith and Co., and subsequently became chief draughtsman and assistant engineer to the Tharsis Sulphur and Copper Co., Glasgow; afterwards he acted in the same capacity to the India Rubber, Guttapercha, and Telegraph Works, Silvertown, London, being associated with many important extensions and reconstructions in both concerns. In 1884 he was appointed manager at the Rio Tinto Copper Co.'s Works at Cwm Avon, South Wales. These works had been disused for some time, and were virtually reconstructed by him and put into working order on modern lines. In 1888 he became manager to the Phœnix Metal Die and Engineering Co., Blackfriars, London, producing among other things iron folding gates. Eventually he entered into partnership, and bought the business, continuing and extending the manufacture of folding gates. His health having failed, he was ordered perfect rest, and retired to Cwm Avon, where his death took place on 8th June 1901, at the age of fifty-seven. He became a Member of this Institution in 1891.

Frederick Pattison Pullar was born at Bridge of Allan, on 20th December 1875, and was the only son of Mr. Laurence Pullar, and nephew of Sir Robert Pullar of Perth. Having been educated by private tutors and at the High School of Stirling, he attended the Glasgow and West of Scotland Technical College from 1893 to 1895. At the end of the latter year he entered his father's dyed and printed cloth works at Bridge of Allan, where his duties lay chiefly in the engineering department. He took a great interest in meteorology and deep-sea soundings, and, in conjunction with Sir John Murray, undertook a systematic survey of all the lochs of Scotland. For this purpose he devised many improvements in the apparatus for taking soundings. His death was of a tragic nature. While several hundred persons were skating on Airthrey Loch, near Bridge of Allan, the ice suddenly gave way, and a number of people were precipitated into the water. He was a strong and powerful swimmer, and at once rushed to the rescue of those who were immersed, plunging into the water with his skates on. Having successfully assisted some to land, he went to the succour of a young lady who was exhausted. Having supported her for some time, they both sank before help reached them. This occurred on 15th February 1901, at the age of twenty-five. He became a Graduate of this Institution in 1897; he was also a Fellow of the Royal Geographical Society, and a Member of the Royal Meteorological Society.

Francis Rixson was born at Brimpton, near Reading, on 23rd February 1846. He was educated privately, and brought up to country pursuits. In 1871 he entered the works of Messrs. Jessop and Co., Sheffield, and passed through the converting and melting shops. In 1873 he left their employment, and entered the works of Messrs. Brown, Bayley and Co., Sheffield, becoming foreman assistant in the Bessemer shops. Later on he had charge of the melting shops, and control of all manufactures other than those of railway materials. In 1881 he entered into partnership with Mr. Woodhouse, and the firm then commenced the manufacture of engineers' forgings, bent cranks, and tool steel, at the Chantrey Works, Attercliffe, Sheffield. His death resulted from an accident at his works. He was witnessing the testing of a large new overhead travelling-crane, which had only recently been erected, when the manager became aware that something was going wrong with the working of the crane. Under the impression that it was collapsing, he seized Mr. Rixson and tried to push him out of harm's way. A piece of the crane fell on some loose iron bars on the ground, causing one of these to fly upwards. This missile struck him under the chin with such force that his neck was broken. His death occurred on 2nd July 1901, at the age of fifty-five. He became a Member of this Institution in 1898.

William Henry Thomas was born in Camberwell, London, on 8th June 1834. He was educated at Sherborne School, and King's College, London. After some work in Russia under the late Mr. F. T. Turner, he became a pupil of the late Mr. (afterwards Sir) John Fowler in 1853. From 1857 to 1870 he was chief assistant to Mr. Turner, taking sole charge of all the work in which he was engaged; this included the Herne Bay and Faversham Railway, the Sevenoaks line, the London Chatham and Dover Railway from Strood to London, and other lines. On the retirement of Mr. Turner, he began to practise on his own account, being appointed engineer to the Cornwall Minerals Railway. He also carried out the Manx Northern Railway in 1877, and during the next few years laid out several lines in various parts of the country. During later years he was employed in widening the River Ouse and making locks at Wisbech and at Dartford, and also in laying out many light railways in the south of England and the Midlands. The ironwork for the Custom House warehouses at Valparaiso, in which 25,000 tons was used, was designed by him; and on the Manx Northern Railway the locomotives, carriages, and wagons were all carried out from his designs. Altogether between 500 and 600 miles of line were personally laid out by him. He contributed to this Institution two Papers on Barton and West's Water Pressure-Reducer * and Piston Water-Meter. His death took place, after a short illness, at Belvedere, Kent, on 24th October 1901, in his sixty-eighth year. He became a Member of this Institution in 1874.

James Walton was born in Liverpool on 22nd February 1820. At the age of fourteen he was apprenticed to Messrs. Fawcett, of Liverpool, for a term of seven years. On its termination he remained for a short time with the firm, and then removed to Woolwich where he was employed for about four years in the marine-engine factory of the Royal Dockyard. He next was engaged by Messrs. Day, Summers and Co., marine engineers at Southampton, by whom he was sent to Alexandria as superintending engineer on a new steamer which they had built for the Peninsular and Oriental Steam Navigation Co. So pleased were the firm and the Egyptian Government with the way in which he performed his duties, that he was appointed superintendent of a line of steamers which the Egyptian Government supplied for the transit of Indian passengers from Alexandria to Cairo. In those days the journey from Cairo to Suez was across the desert, re-embarking at Suez for India and China. On the completion of the railway from Alexandria to Suez, he was appointed locomotive superintendent, which post he retained until his retirement in 1874. In recognition of his long service with the Egyptian Government, the Khedive created him a Bey. His death took place at his residence at Old Charlton, Kent, on 11th May 1901, at the age of eighty-one. He became a Member of this Institution in 1877.

William Whiteley was born at Lockwood, near Huddersfield, on 18th March 1850, and was the third son of Mr. William Whiteley, founder of the firm of William Whiteley and Sons, textile machinery makers and electrical engineers, Prospect Works, Lockwood. He

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* Proceedings 1879, pages 434 and 444.

was educated at King James's School, Almondbury, and afterwards at the College, Ripponden. In 1866 he commenced his business career at his father's works in the pattern shop and drawing office. After the death of his father, he joined his two elder brothers in partnership, and took a leading part in the conduct of the business. Among his many inventions were improvements in machines for drying, spinning, warping, sizing, and finishing wool; he also designed special labour-saving tools, and took an active part in the organisation and development of the works. Latterly he was one of the initiators in adding the manufacture of machinery for electrical equipment. Some years ago, in the course of a trip round the world, he witnessed the operation of sheep-shearing up country in Australia, when unfortunately some of the wool dust found its way into his bronchial passages, causing severe hemorrhage of the lungs, since which he had laboured under a weakness of that organ. Whilst at Southport he contracted a chill, which resulted in bronchitis. Returning home to Holly Mount, Edgerton, near Huddersfield, he grew worse, and his death took place on 8th July 1901, at the age of fifty-one. He became a Member of this Institution in 1876.

Charles Louis Napoleon Wilson was born in Blackburn on 28th August 1867, and was educated at the Mount Pleasant Wesleyan Schools, and the Collegiate Grammar School, Bacup. He afterwards went to Owens College, Manchester, where he came out third in the first class in civil engineering. From 1881 to 1886 he served his time under his father, the borough engineer of Bacup, and then acted as assistant borough engineer for over five years. In 1890 he won the first prize in an open competition for the Bacup Public Baths; and he prepared the surveys, plans, and sections for the Stacksteads Sewage Works. He also had charge of the construction of the Rossendale Valley steam tramway in the borough. In 1891 he was appointed Town Surveyor of Bilston, where, in addition to his ordinary duties, he designed and carried out the erection of an electric lighting plant at the Market House; the electric lighting, heating, and laundry machinery at the Baths; and gas-engine and machinery at the Bilston Technical Schools. He also acted for over five years as resident engineer on the Bilston Water Works, under Mr. Baldwin Latham, of Westminster. For a number of years he had been engaged in making experiments on the precipitation and artificial filtration of sewage, and also on sewage disposal and bacteriology. He was an enthusiastic volunteer, being a captain in the 3rd V.B. South Staffordshire Regiment, and was a Lieutenant in the Army Reserve of Officers. In the latter capacity he was called out to duty with the details of the Royal Dublin Fusiliers, from July to October 1900, with the rank of Captain. On receiving an appointment under Government, he tendered his resignation to the Bilston Council, and proceeded to South Africa, landing at Durban on 9th October 1901. He then proceeded to Chinde, where his death took place from enteric contracted on the voyage, on 15th November 1901, at the age of thirty-four. He became a Member of this Institution in 1899.

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Hardwick, E. J., elected Associate Member, 1026.

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Nevill, S. S., elected Graduate, 1028.

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Newton, P., elected Graduate, 499.

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Oughterson, G. H., elected Associate Member, 498.

Page, H. A., elected Associate Member, 1027.

Page, J. H., elected Associate Member, 1027.

Palmer, A., elected Associate Member, 1027.

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Parks, W. A., elected Associate Member, 498.

Parr, G. D. A., elected Associate Member, 498.

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Peacock, J. B., elected Graduate, 1028.

Peake, A. C., elected Graduate, 1028.

Peart, J., elected Member, 1026.

Percy, F., elected Associate Member, 1027.

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Prevôst, A. T., elected Graduate, 1028.

Pritchard, R. C., elected Associate Member, 1027.

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Rainforth, W. F., elected Associate Member, 1027.

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Stormont, P. C., elected Member, 497.

St. Paul, C., elected Associate Member, 1027.

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THOMPSON, F. W., elected Associate Member, 499.

THOMSON, C., elected Member, 497.

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THORPE, W. B., elected Associate Member, 499.

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True, R. A., elected Associate Member, 499.

Tullis, D. K., elected Member, 497.

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Turner, E. W., elected Graduate, 1028.

Turner, W. W., elected Graduate, 1028.

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Vaughan, C., elected Member, 1026.

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Wadham, E., Remarks at Institution Dinner, Barrow-in-Furness, 741.

Wadia, N. N., elected Member, 1026.

Walkem, G. A., elected Associate Member, 499.

Walker, A., elected Associate Member, 1027.

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Walker, R., elected Associate Member, 499.

Walker, R. H., elected Associate Member, 1027.

Walker, T. A., elected Graduate, 499.

Wallace, C. P., elected Graduate, 1028.

Waller, W., elected Associate Member, 1027.

Walmsley, C., elected Member, 497.

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Walsh, T., elected Associate Member, 1027.

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Warwick, P. W., elected Graduate, 1028.

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Webb, T. H., elected Member, 1026.

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WHITE, P. W., elected Graduate, 1028.

WHITE, R., elected Member, 497.

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WILLEY, L. A., elected Graduate, 1028.

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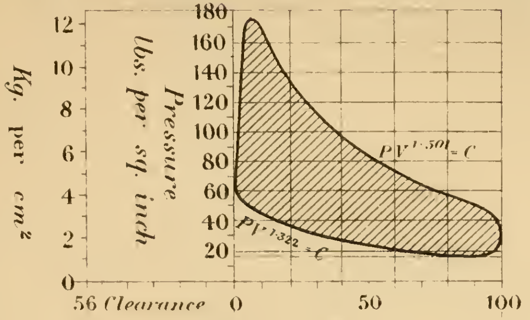
WRIGHT, W., elected Member, 497.

YOUNG, H. E., elected Associate Member, 1027.

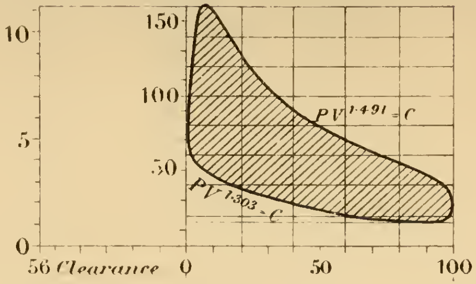
GAS-ENGINE RESEARCH.

Trials A.

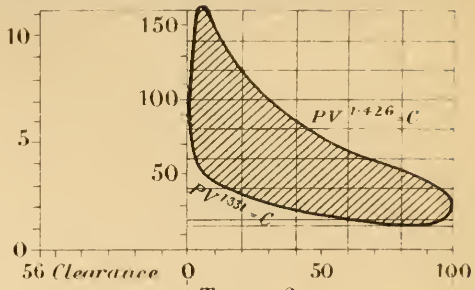
Test 1.
M.P.= 4·51 *Kg.cm*^{2}; 64 *lbs.* □". I.P.=3·81 *Kw.* 5·11 H.P.



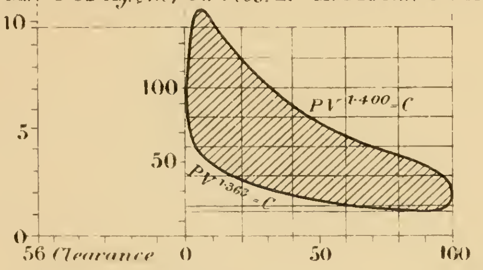
Test 2.
M.P.=4·20 *Kg.cm*^{2}; 59·7 *lbs.* □". I.P.=3·49 *Kw.* 4·68 H.P.



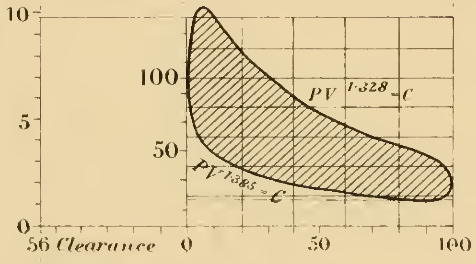
Test 3.
M.P.=4·00 *Kg.cm*^{2}; 56·9 *lbs.* □". I.P.=3·38 *Kw.* 4·53 H.P.



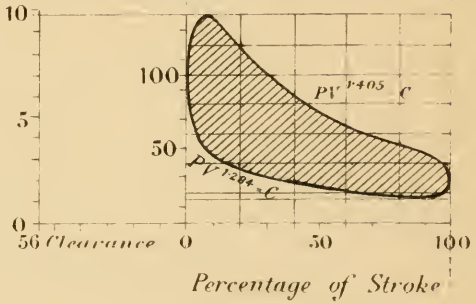
Test 4.
M.P.=3·92 *Kg.cm*^{2}; 55·7 *lbs.* □". I.P.=3·29 *Kw.* 4·4 H.P.



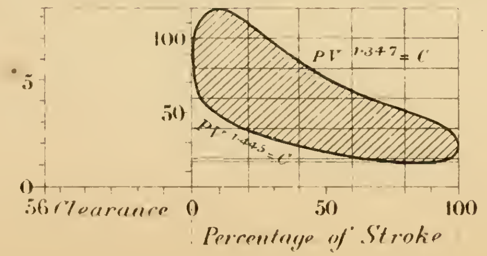
Test 5.
M.P.=3·76 *Kg.cm*^{2}; 53·5 *lbs.* □". I.P.=2·95 *Kw.* 3·95 H.P.



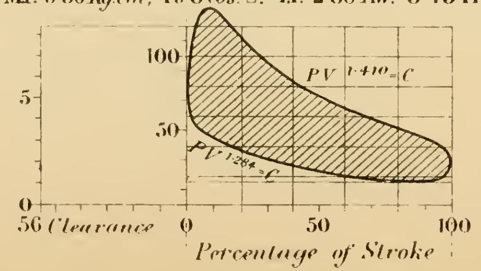
Test 6.
M.P.=3·82 *Kg.cm*^{2}; 54·3 *lbs.* □". I.P.=3·16 *Kw.* 4·24 H.P.



Test 7.
M.P.=3·33 *Kg.cm*^{2}; 47·4 *lbs.* □". I.P.=2·88 *Kw.* 3·86 H.P.



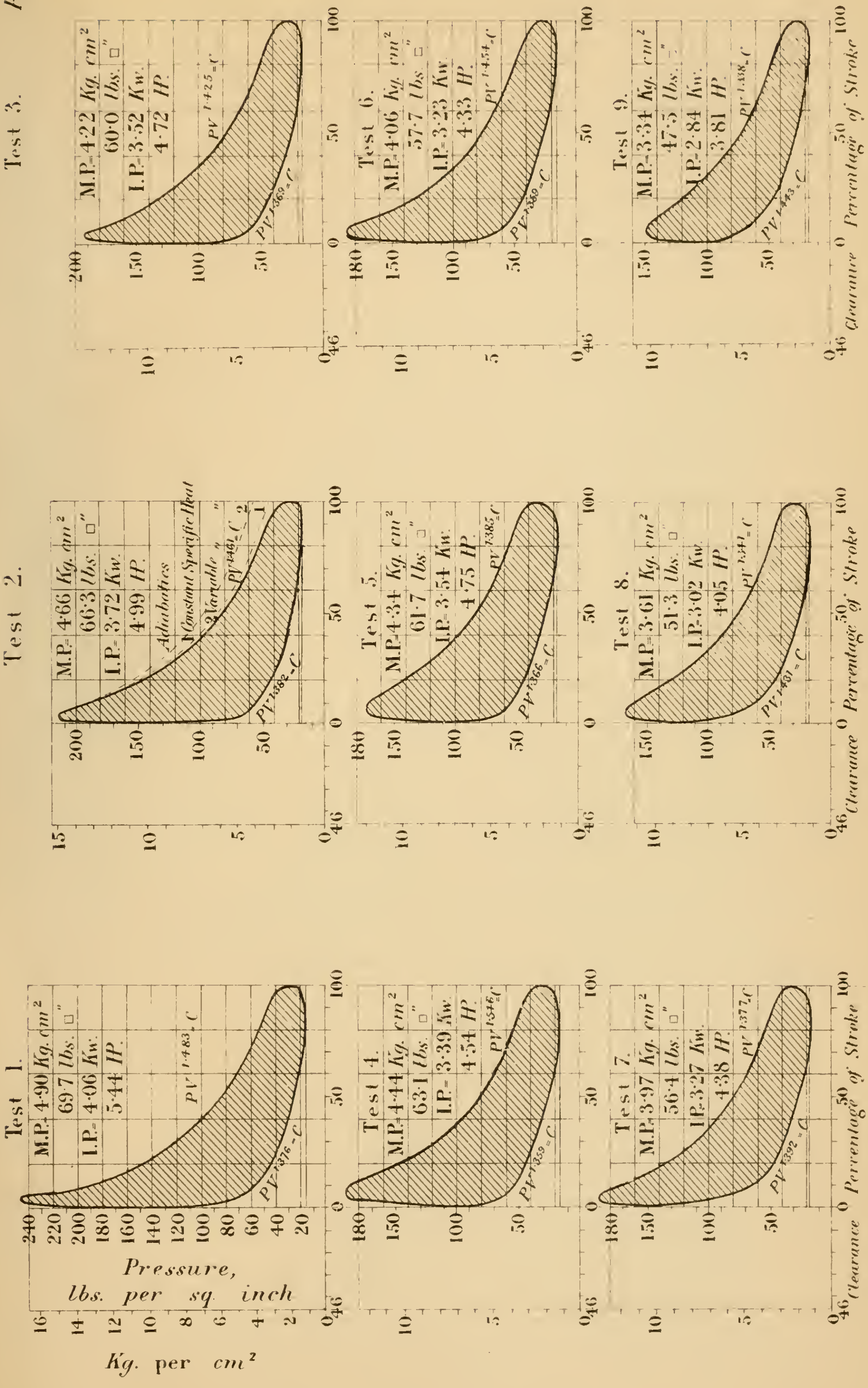
Test 8.
M.P.=3·50 *Kg.cm*^{2}; 49·8 *lbs.* □". I.P.=2·80 *Kw.* 3·75 H.P.



C. = *Constant*
M.P. = *Mean Pressure*
I.P. = *Indicated Power*
Kg cm^2 = *Kilogrammes per square centimetre*
Lbs. □" = *Pounds per square inch*

GAS-ENGINE RESEARCH.

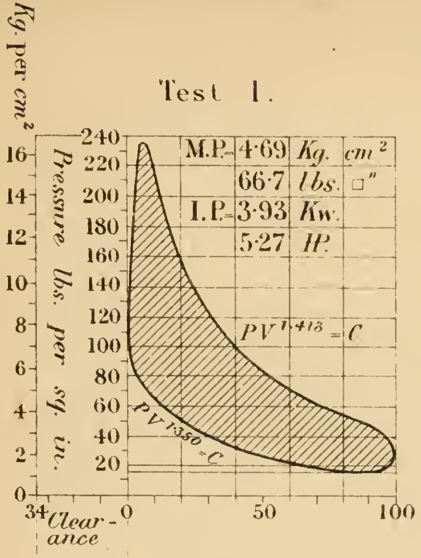
Trials B.



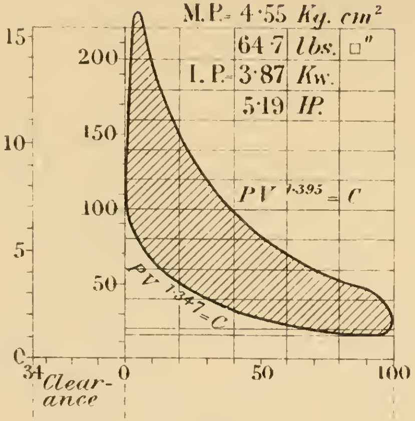
GAS-ENGINE RESEARCH.

Trials C.

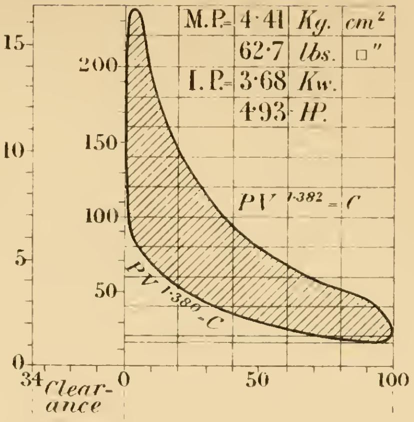
Test 1.



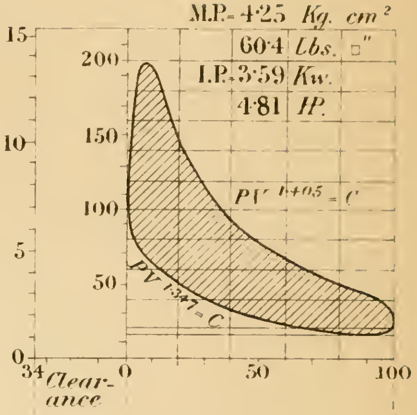
Test 2.



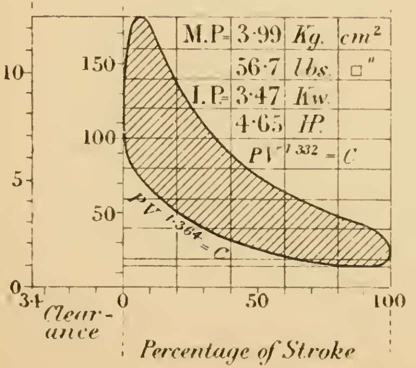
Test 3.



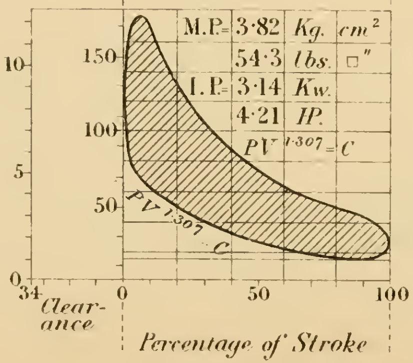
Test 4.



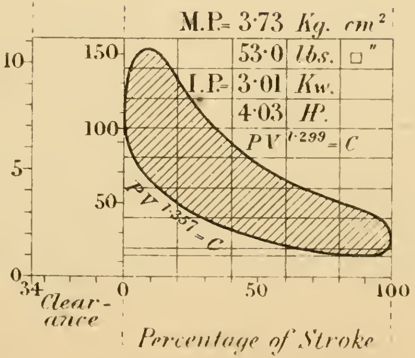
Test 5.



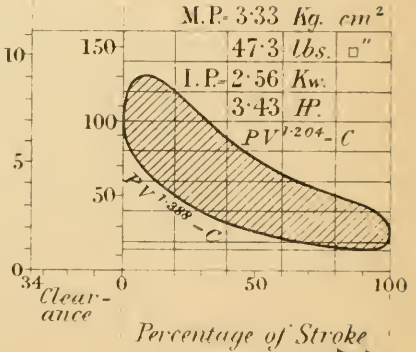
Test 6.



Test 7.



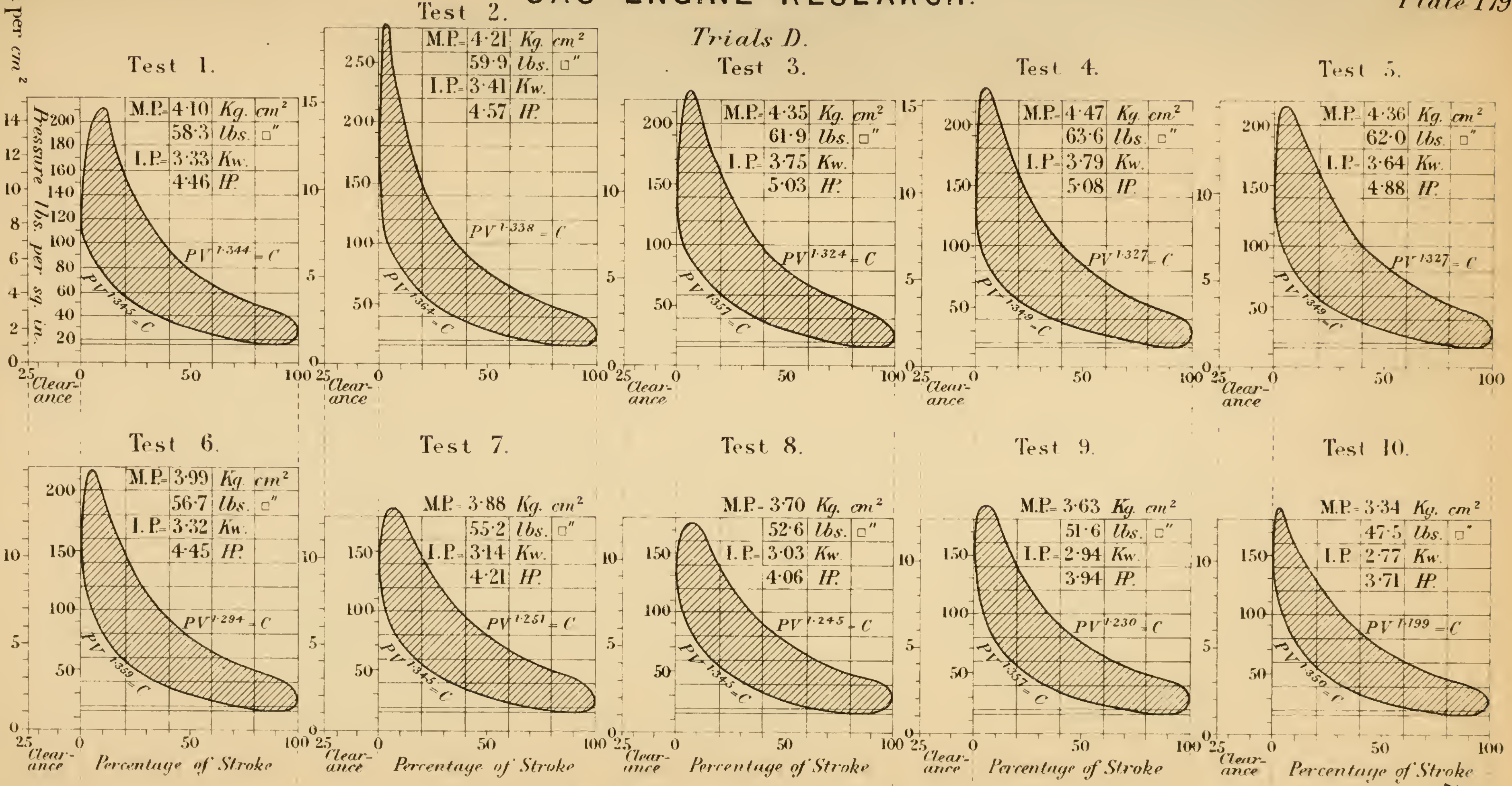
Test 8.



Mechanical Engineers 1901.

GAS-ENGINE RESEARCH.

Trials D.



GAS-ENGINE RESEARCH

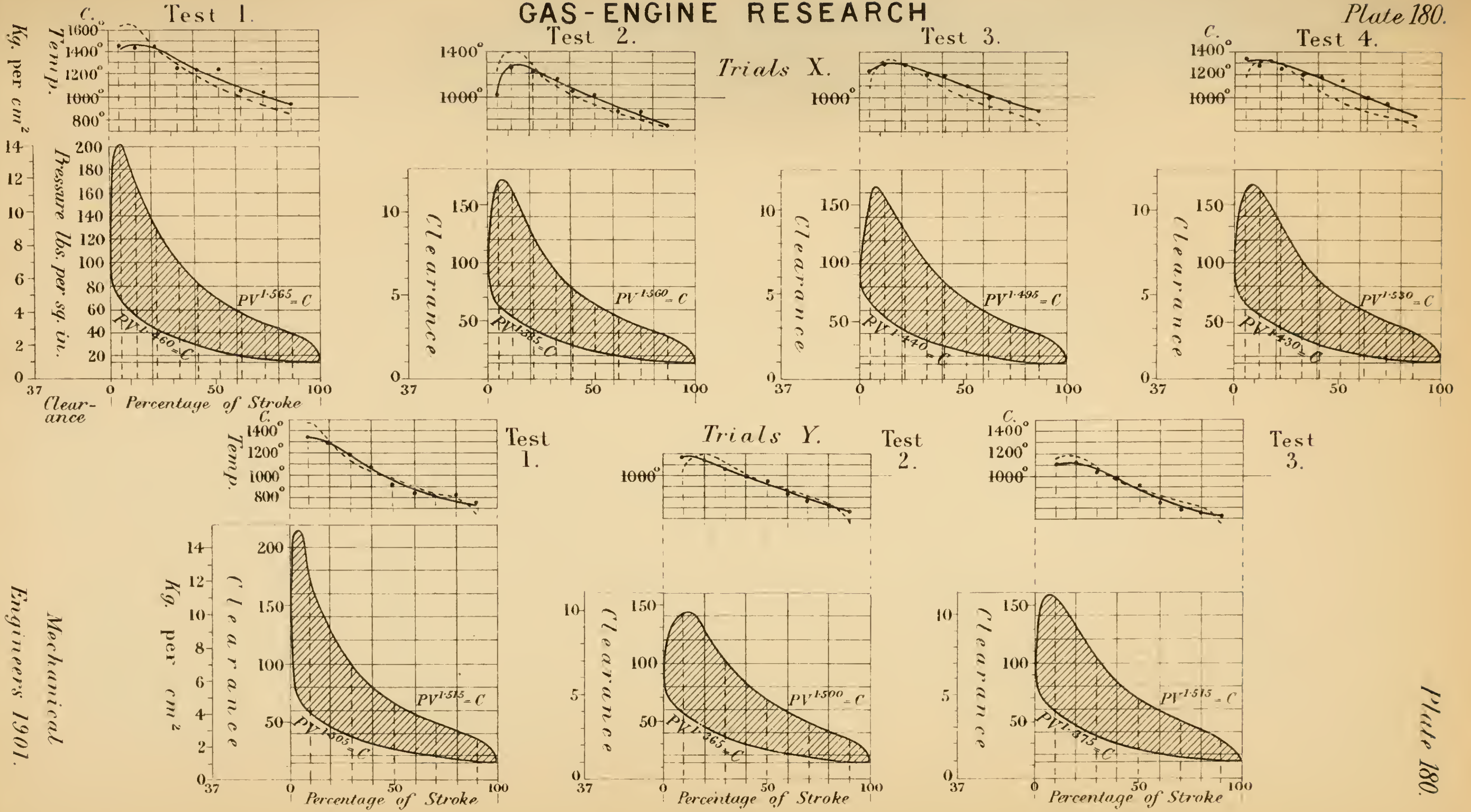
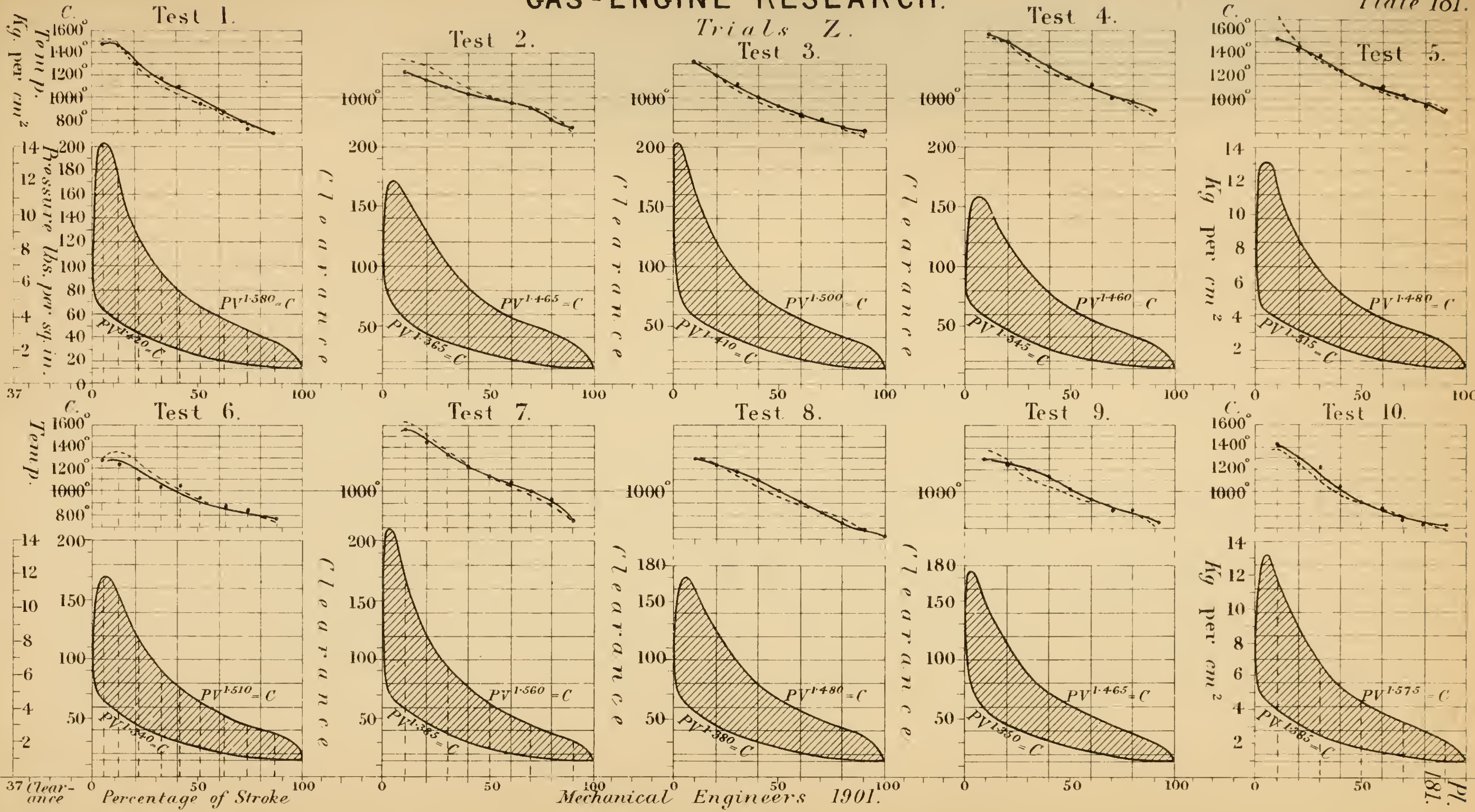


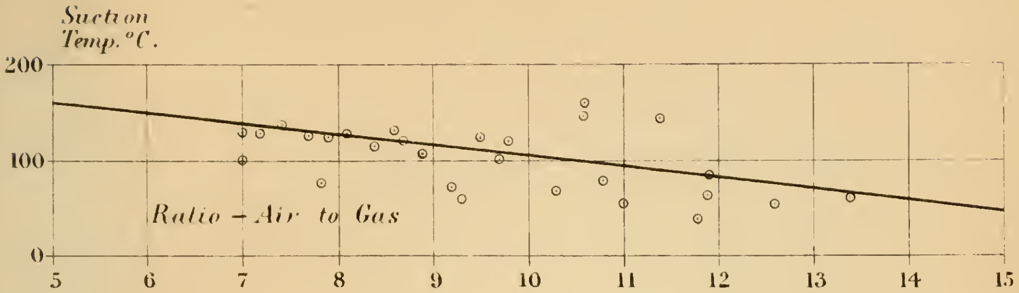
Plate 180.

GAS-ENGINE RESEARCH.

Trials Z.

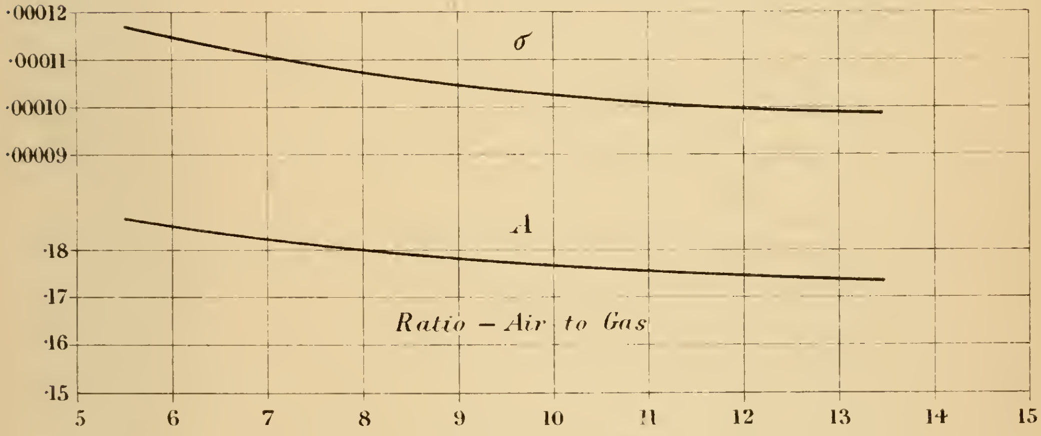


Relation of Suction Temperature and Air to Gas.



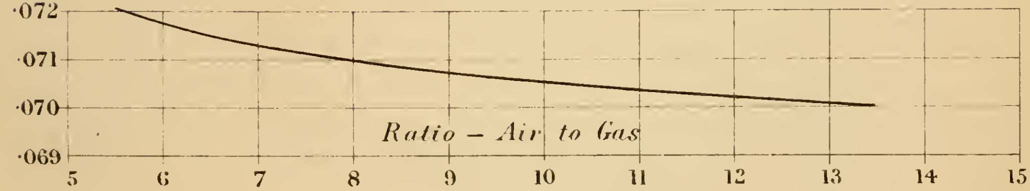
Relation of Specific Heat at Constant Volume to Ratio of Air to Gas.

$$K_v = A + \sigma t^o$$



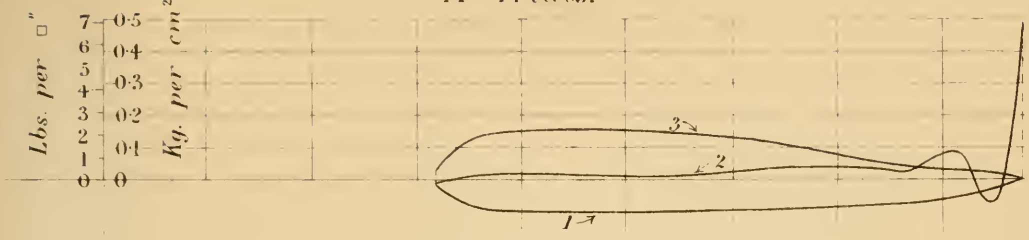
Relation of Gas Constant to Ratio of Air to Gas.

$$R = K_p - K_v$$

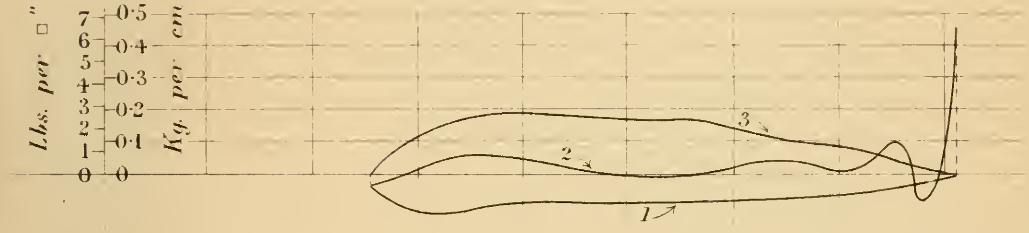


Pumping Diagrams.

A Trials.

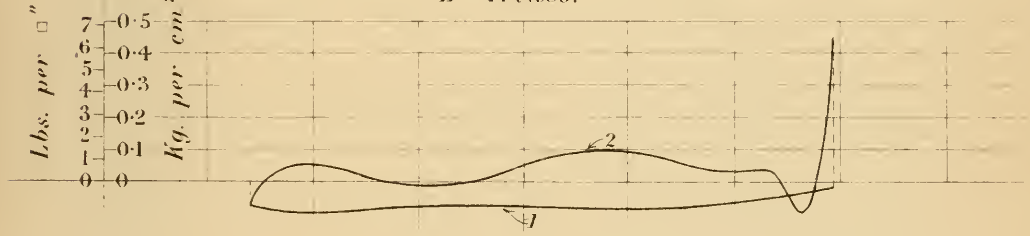


B Trials.

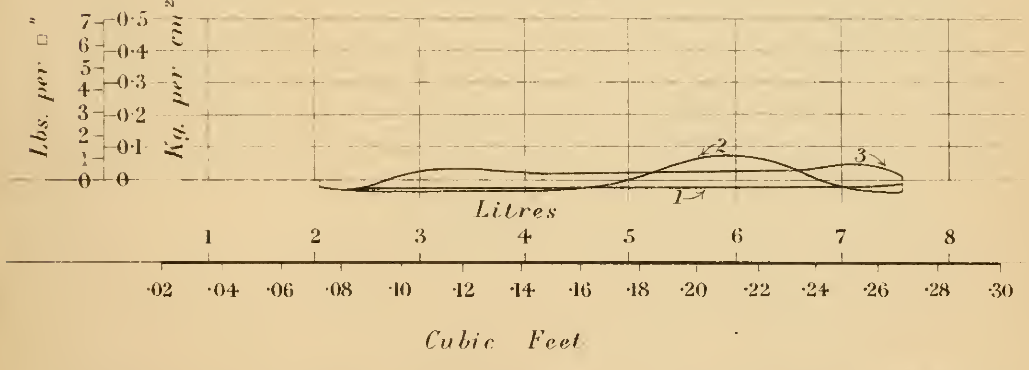


(C Trials omitted.)

D Trials.



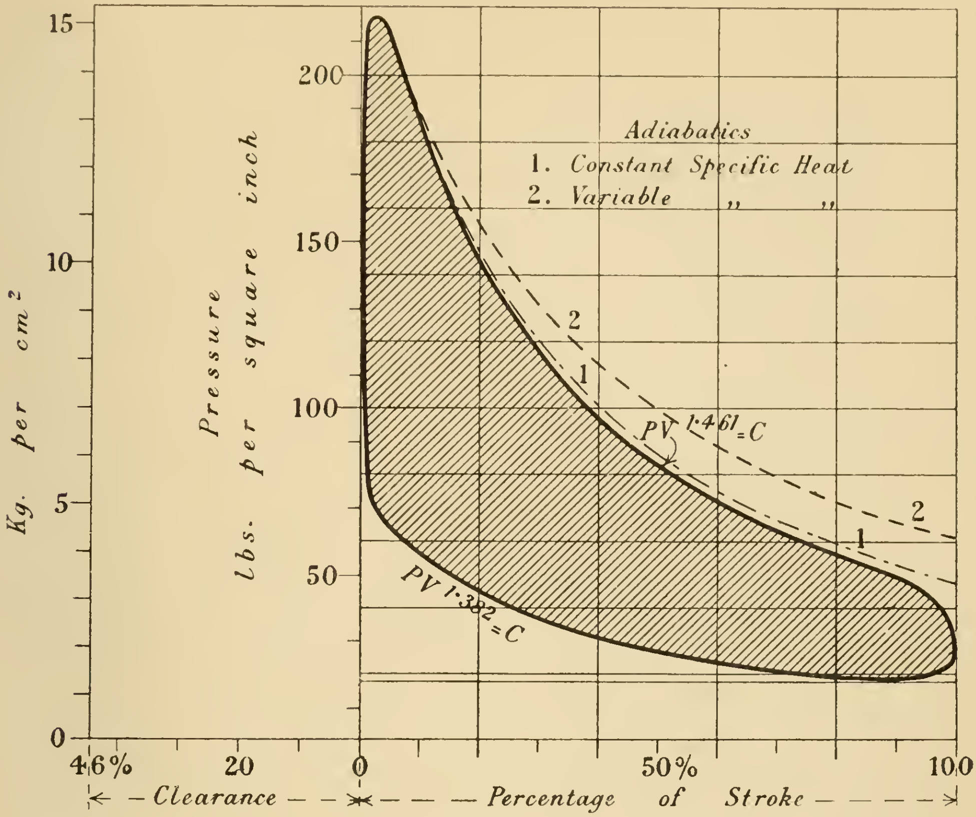
X.Y. Z. Trials.



1 = Suction. *2 = Exhaust after Explosion.* *3 = Exhaust after Missfire.*

Trials B. Enlargement of diagram. Test 2. (See Plate 177.)

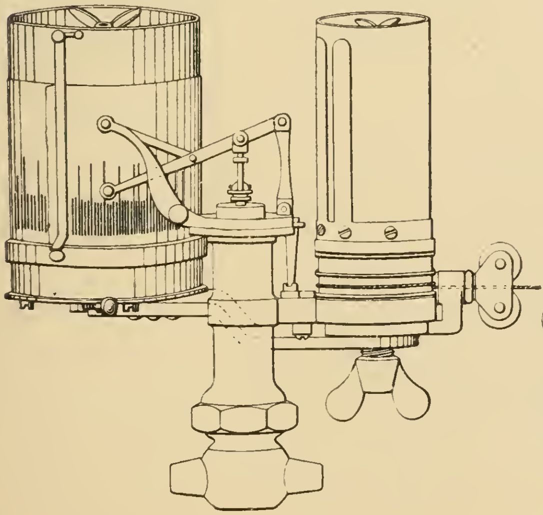
M.P. = 4·66 *Kg.cm*^{2} 66·3 *lbs. per sq. in.* I.P. = 3·72 *Kw.* 4·99 *H.P.*

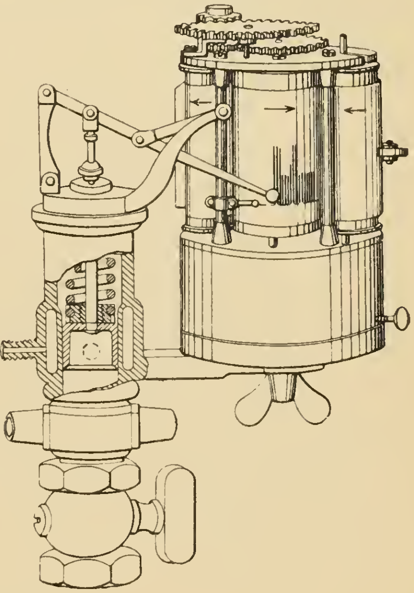


Continuous Recorders for Gas or Oil-Engines (Mathot).

Fig. 12. *(Mr. Bryan Donkin's remarks.* Fig. 13.

For any existing Indicator. *For High Speeds.*





Diagrams taken by Recorder, Fig. 12.

Fig. 14. *12 H.P. Oil-Engine.* ($^2/_3$rds *original.*)

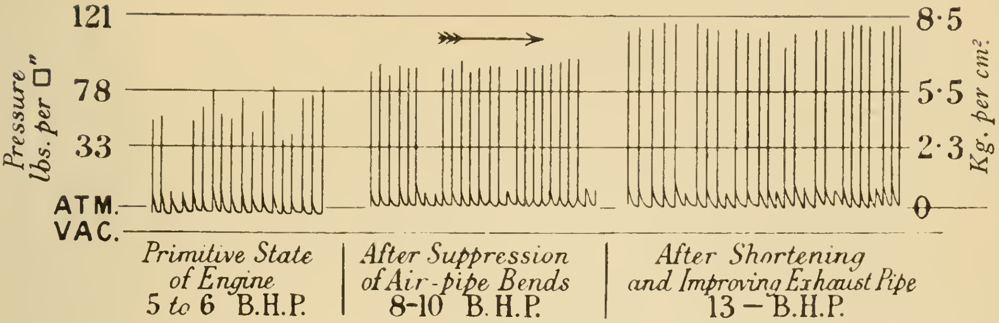


Fig. 15. *Variable Pressures on Starting a Gas-Engine.* ($^1/_2$ *original.*)

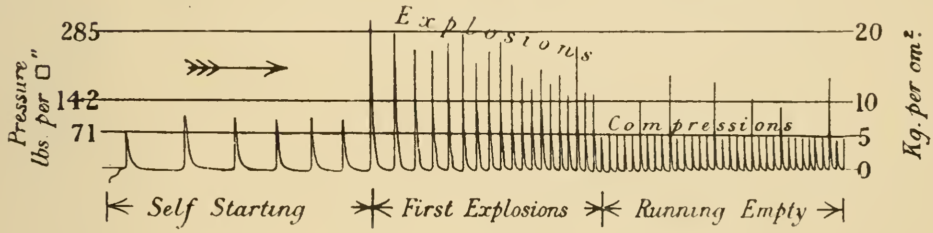


Fig. 16. *Gas-Engine.* ($^1/_3$rd *original.*)

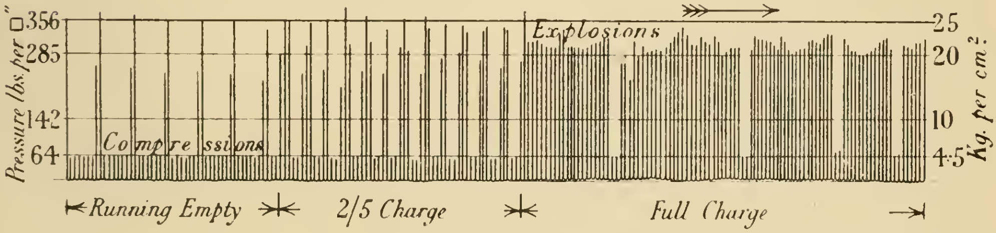
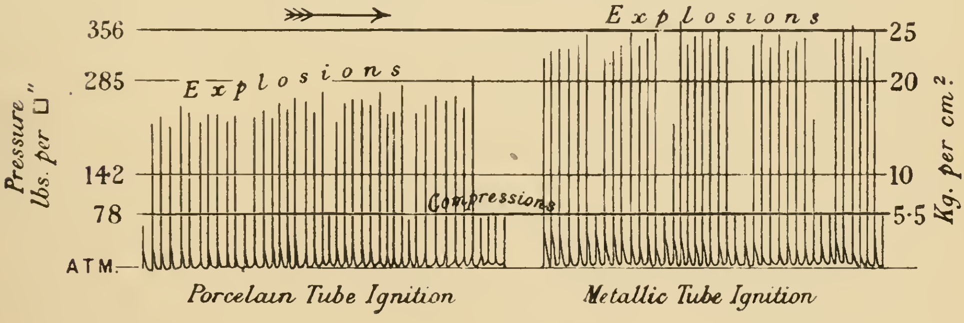


Fig. 17. *Gas-Engine.* ($^1/_2$ *original.*)



Diagrams taken by Recorder, Fig. 12.

Fig. 18. *Gas-Engine.* (½ *original.*)

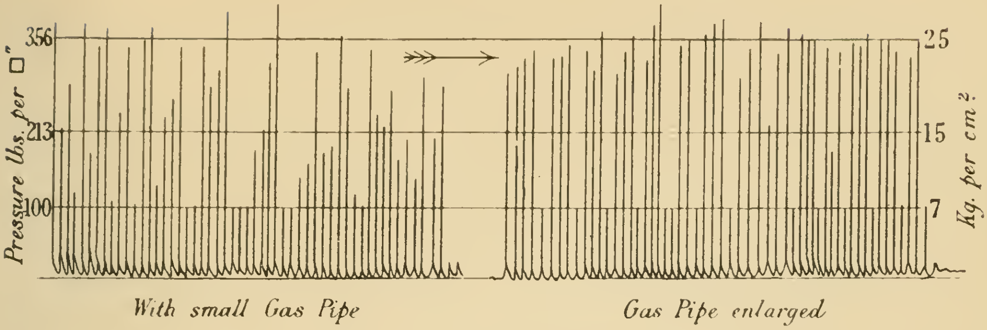
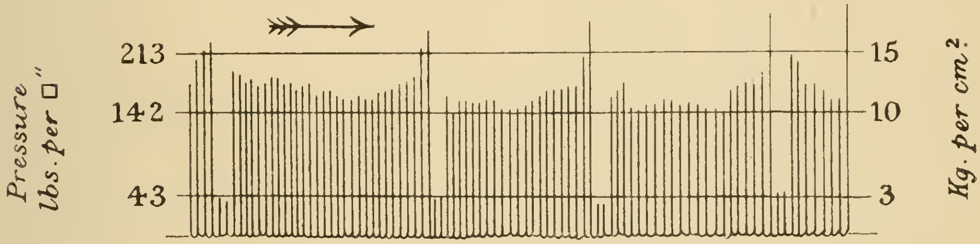


Fig. 19. *Gas-Engine.*



Admission Valve for mixture was too small, and the explosions failed to attain their maximum pressures without a gradual decrease of speed of the engine.

Fig. 20. *Gas-Engine, working half load.* (½ *original.*)

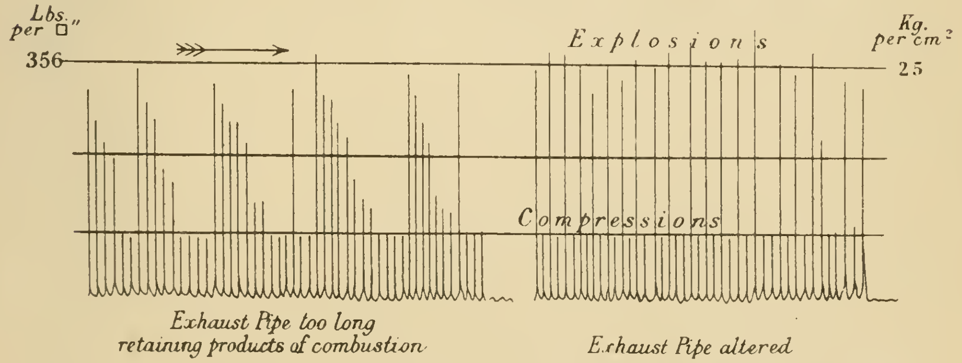
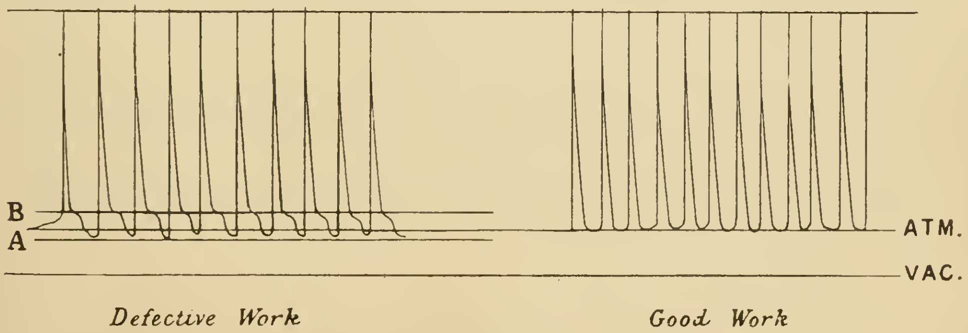


Fig. 21. *Taken by Recorder, Fig 13, on a Motor-Car Engine.*

Influence of the Size of Suction and Exhaust Pipes and Valves

A = *Vacuum due to Suction* $\frac{1}{10}$ ATM.
B = *Pressure* „ „ *Exhaust* $\frac{3}{10}$ ATM.

Gain of Power due to correction of Valves and Pipes 29%



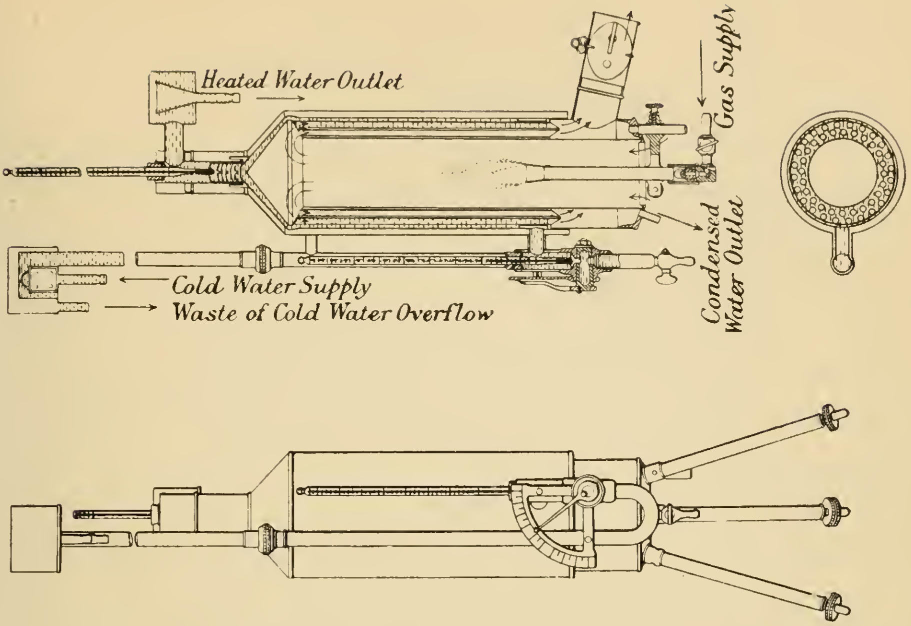


Fig. 23. *Calorimeter. (Junkers'). Pl. 187.*

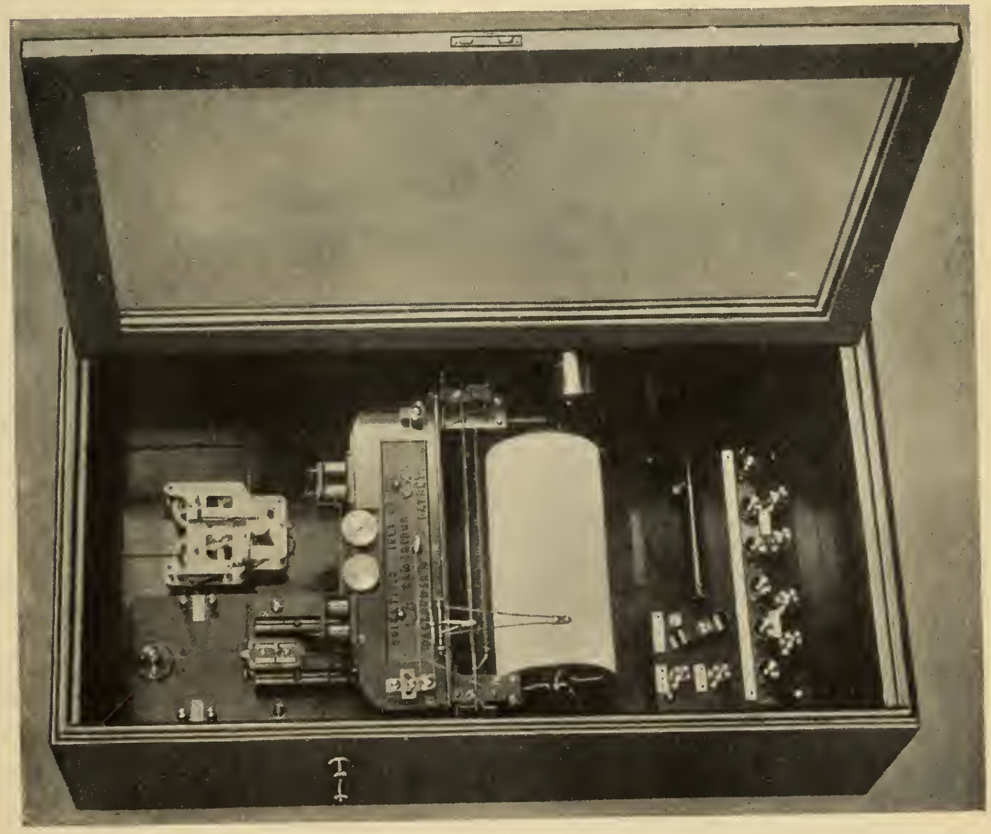


Fig. 22. *Recording Thermometer. (Callendar.)*

Fig. 21. *Suspended Four-crank Model. Reciprocating parts adjustable.*

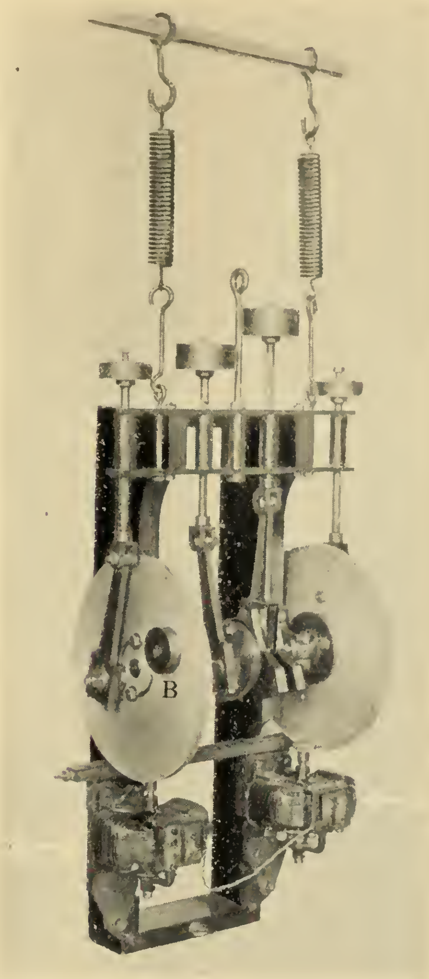
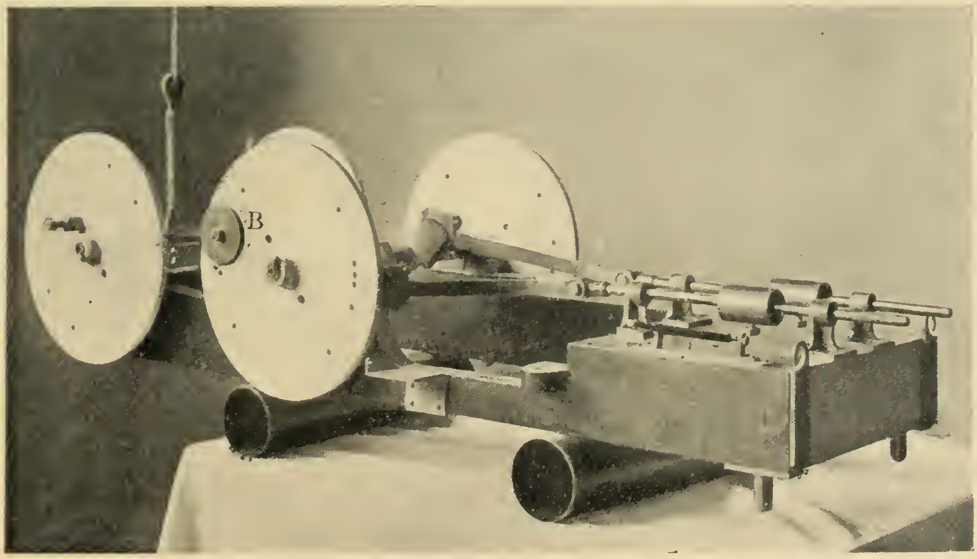


Fig 22. *Locomotive Model. On rollers and partially suspended.*



Pyrometer-Recorder.

Fig. 3. *Front.*

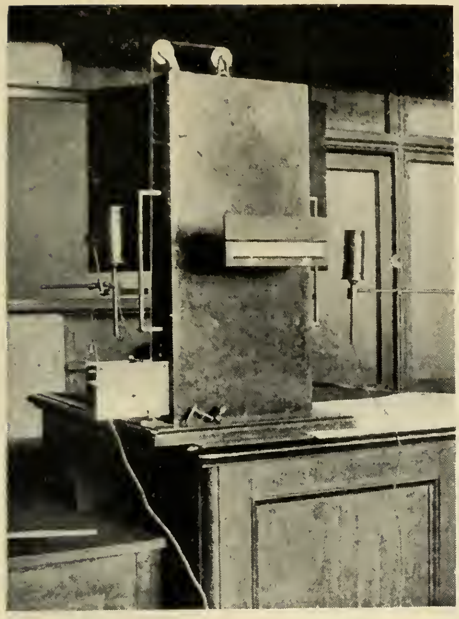


Fig. 4. *Back.*

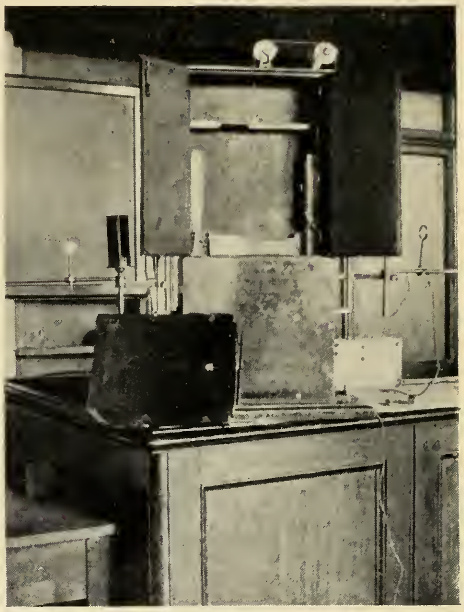
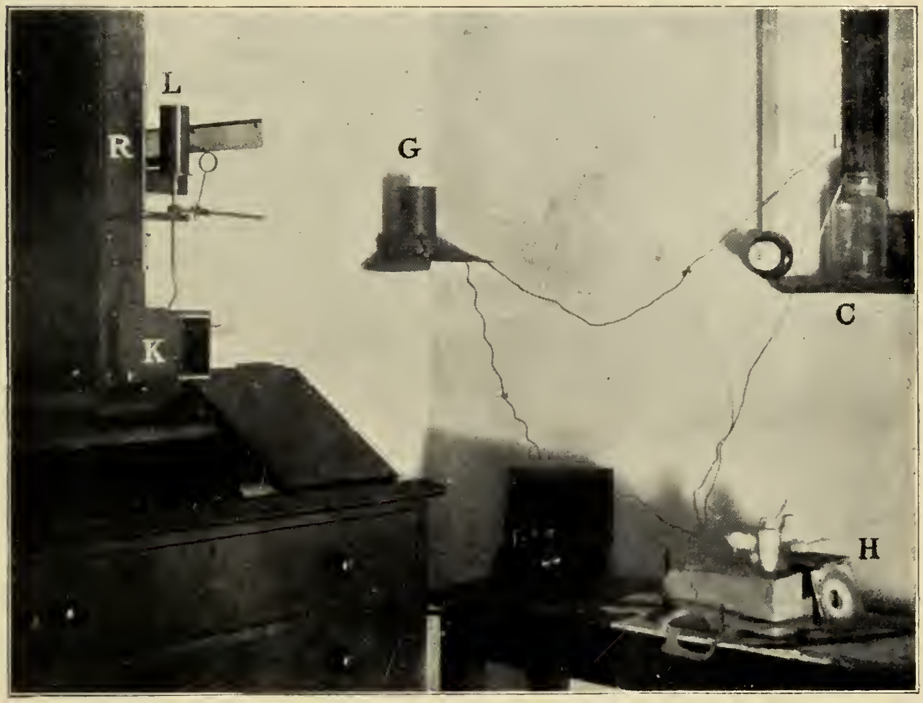


Fig. 5. *In place and in working order.*



L. Light.
R. Recorder.
K. Clock.
G. Galvanometer.
C. Cold Junction of Thermo-Couple.
H. Hot Junction of Thermo-Couple.

Fig. 6.

0·25% Cu. × *20 diams.* *v.*

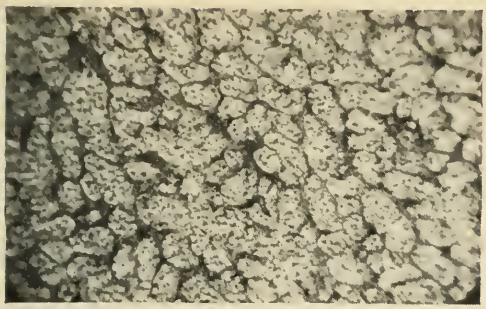


Fig. 7.

0·5% Cu. × *20 diams.* *v.*

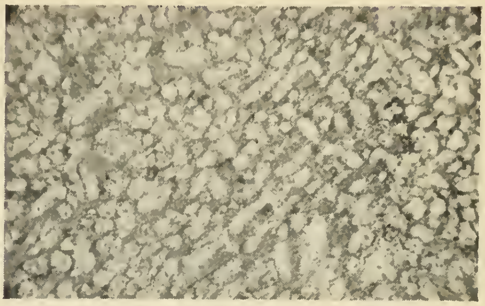


Fig. 8.

0·5% Cu. Cast. × *20 diams.* *v.*

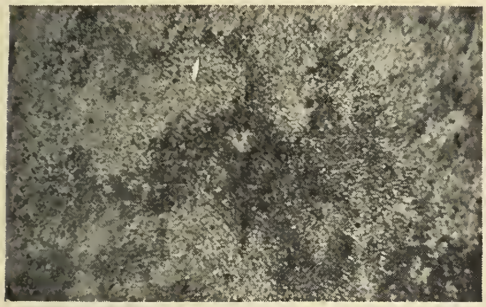


Fig. 9.

0·75% Cu. × *20 diams.* *v.*

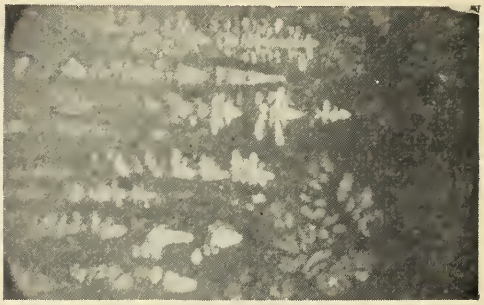


Fig. 10.

1% Cu. × *20 diams.* *v.*

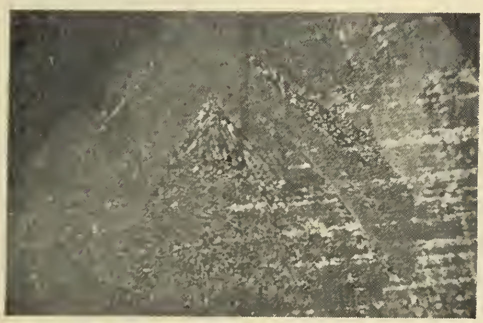


Fig. 11.

1% Cu. Deeply etched. × *20 diams.* *o.*

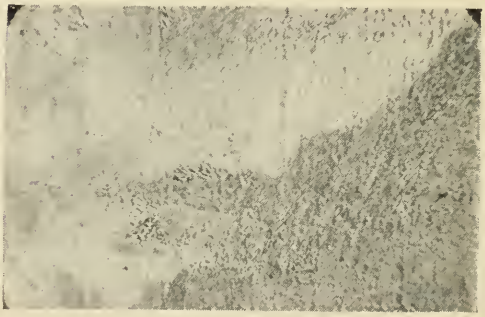


Fig. 12.

1% Cu, f.c. × *20 diams.* *o.*

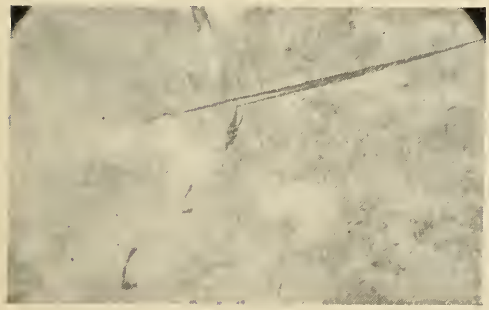
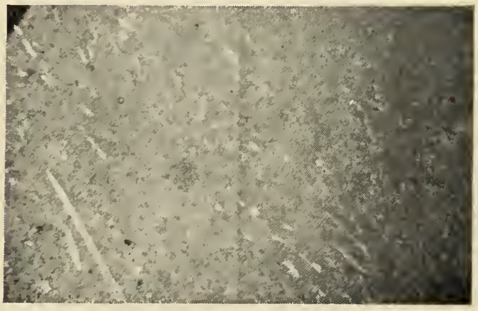


Fig. 13.

1% Cu, f.c. Upper side. × *20 diams.* *v.*



f.c. furnace-cooled. *o.* oblique illumination. *v.* vertical illumination.

Fig. 14. *Crystals.*

1% Cu, f.c. × *20 diams.* *o.*

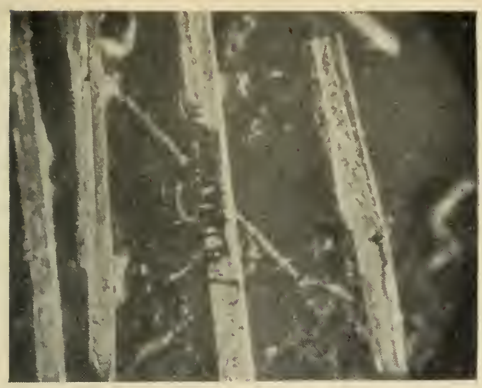


Fig. 15.

2·6% Cu. × *20 diams.* *v.*

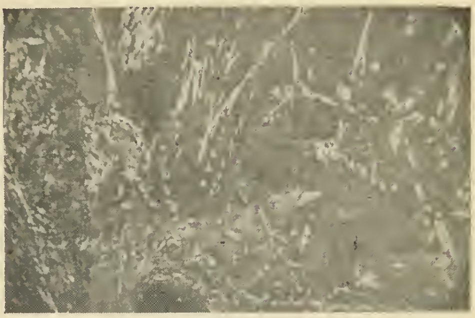


Fig. 16.

5% Cu. × *20 diams.* *v.*

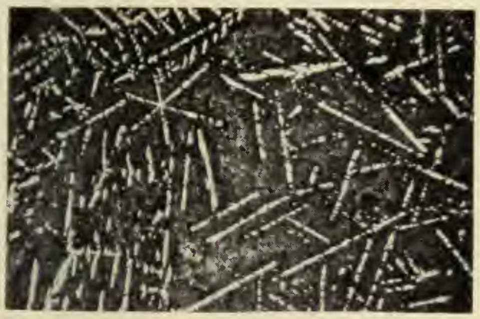


Fig. 17.

5% Cu, f.c. × *20 diams.* *v.*

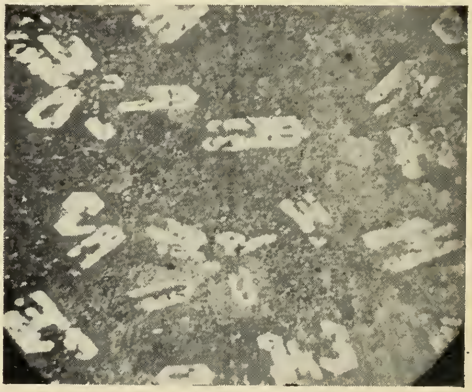


Fig. 18. *Crystals.*

5% Cu, f.c. × *20 diams.* *o.*

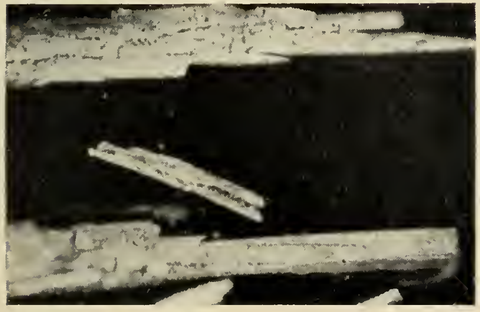


Fig. 19. *Crystals.*

5% Cu, f.c. × *10 diams.* *o.*

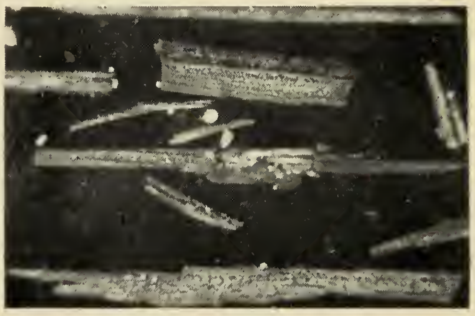
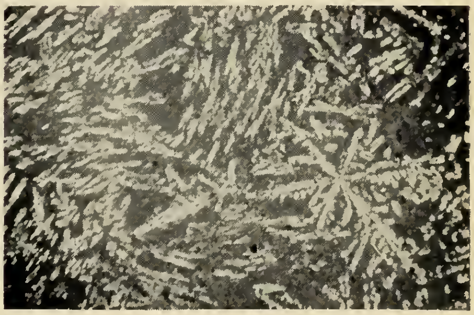


Fig. 20.

5% Cu. Cast. × *20 diams.* *v.*

Fig. 21.

8% Cu. × *20 diams.* *v.*



f.c. furnace-cooled. *o.* oblique illumination. *v.* vertical illumination.

COPPER-TIN ALLOYS.

Fig. 22.

8% Cu. Cast. × *20 diams.* *v.*

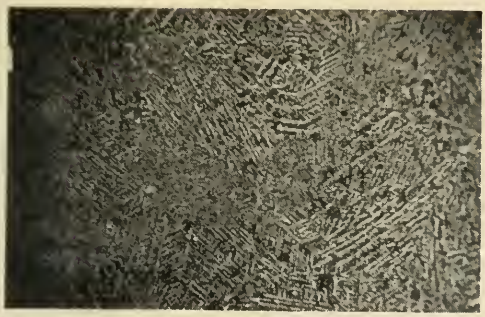


Fig. 23.

10% Cu. × *20 diams.* *v.*

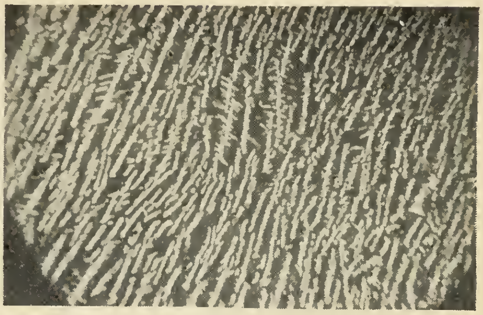


Fig. 24. *Crystals.*

10% Cu. f.c. × *10 diams.* *o.*

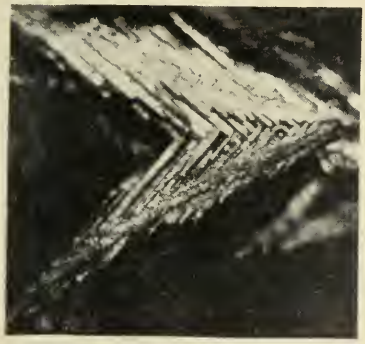


Fig. 25.

10% Cu. f.c. × *20 diams.* *v.*

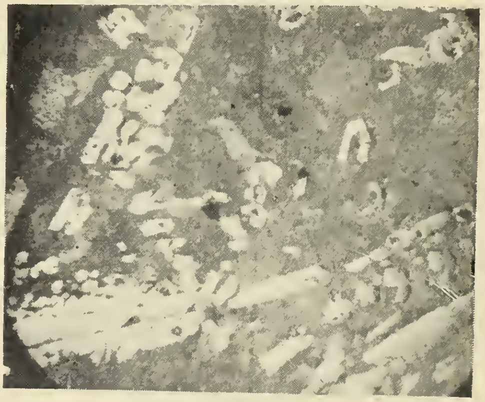


Fig. 26.

10% Cu. f.c. × *20 diams.* *v.*

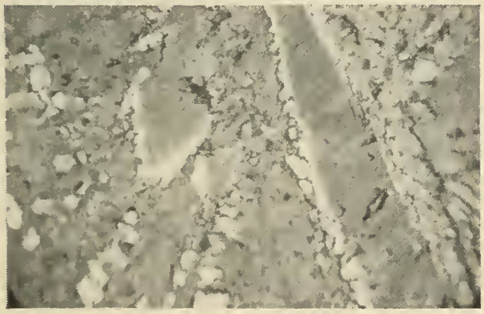


Fig. 27.

10% Cu, Cast. × *20 diams.* *v.*

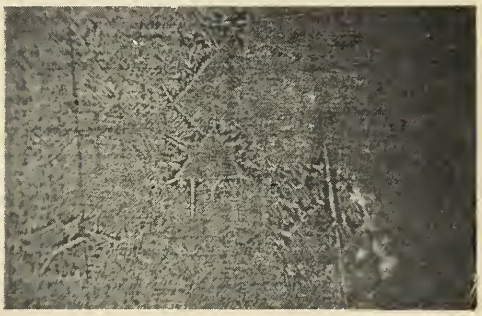


Fig. 28.

20% Cu. × *20 diams.* *v.*

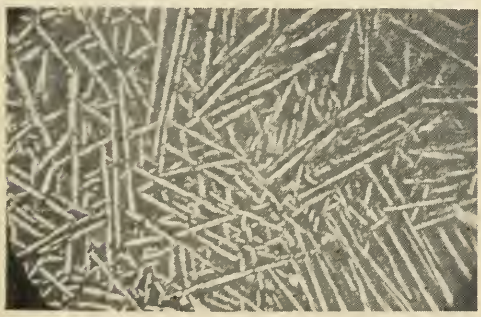
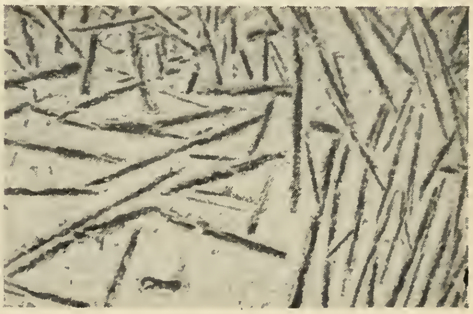


Fig. 29.

20% Cu. × *20 diams.* *o.*



f.c. furnace-cooled. *o.* oblique illumination. *v.* vertical illumination.

Fig. 30.

20% Cu, f.c. × *20 diams.* *v.*

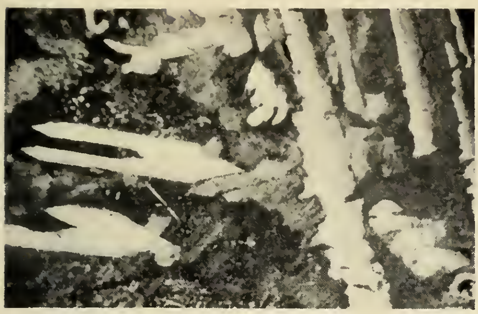


Fig. 31. *Crystal.*

20% Cu, f.c. × *20 diams.* *o.*

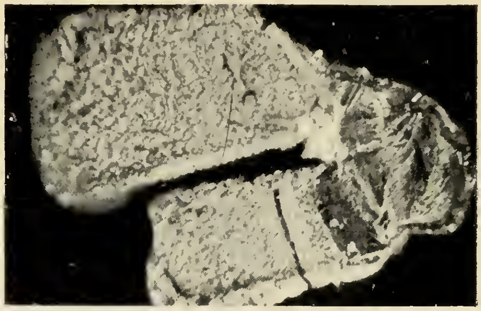


Fig. 32. *Crystal.*

20% Cu, f.c. × *10 diams.* *o.*

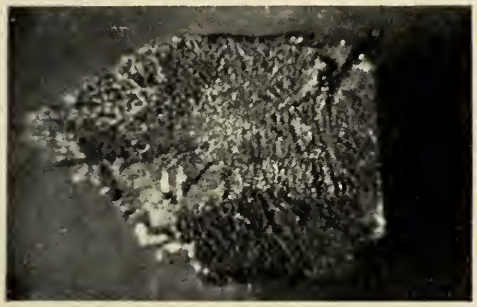


Fig. 33.

20% Cu, f.c. × *20 diams.* *v.*

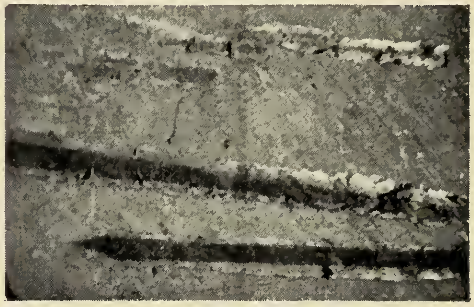


Fig. 34.

20% Cu, Cast. × *20 diams.* *v.*

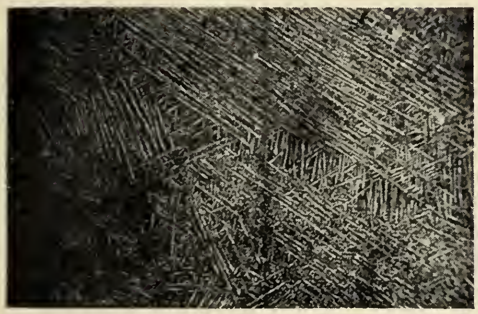


Fig. 35.

30% Cu. × *20 diams.* *v.*

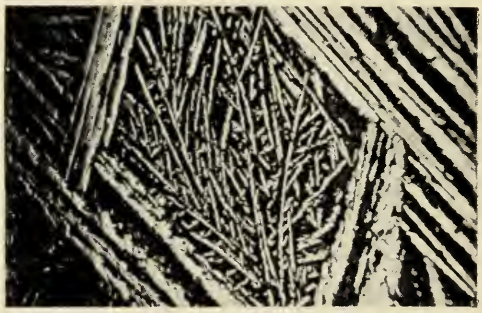


Fig. 36.

30% Cu, Cast. × *20 diams.* *v.*

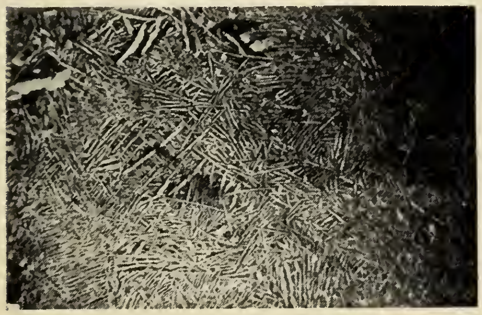
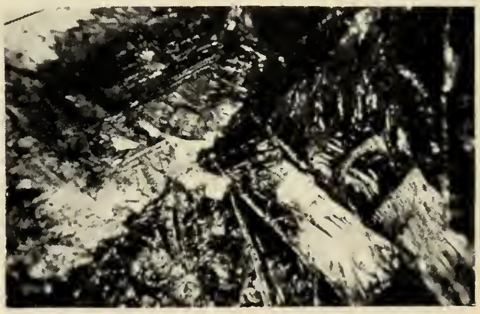


Fig. 37. *Cast. Surface.*

33% Cu. × *20 diams.* *v.*



f.c. furnace-cooled. *o.* oblique illumination. *v.* vertical illumination.

COPPER-TIN ALLOYS.

Fig. 38.

40% Cu. × *20 diams.* *v.*

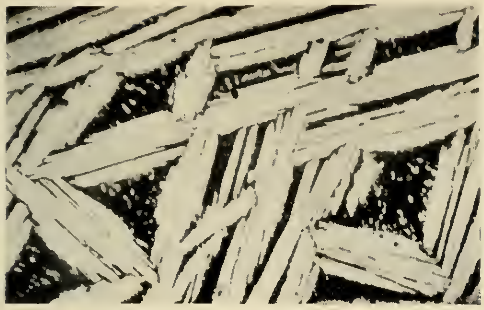


Fig. 39.

10% Cu, Cast. × *20 diams.* *v.*

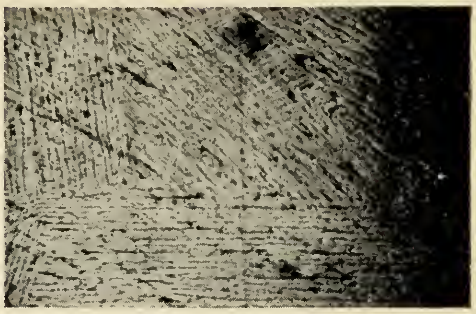


Fig. 40. *Cast. Surface.*

40% Cu. × *20 diams.* *v.*

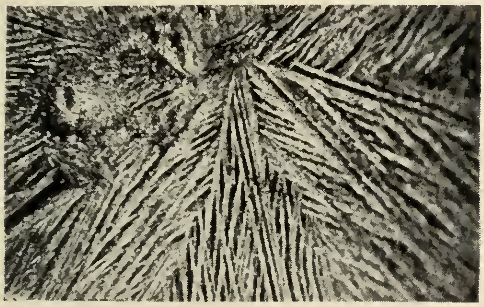


Fig. 41.

41% Cu. × *20 diams.* *v.*

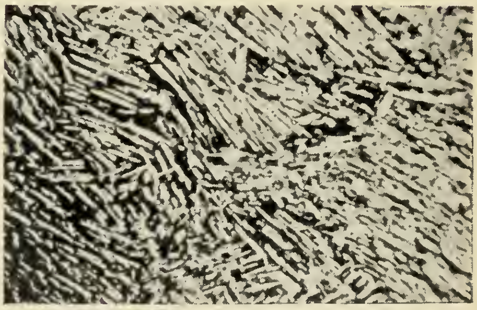


Fig. 42.

43% Cu. × *20 diams.* *v.*

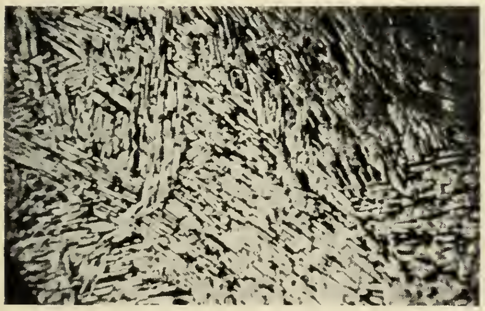


Fig. 43.

43% Cu, Cast. × *20 diams.* *v.*

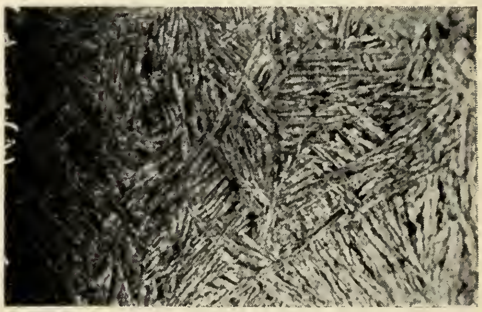


Fig. 44. *Cast. Surface.*

43% Cu. × *20 diams.* *o.*

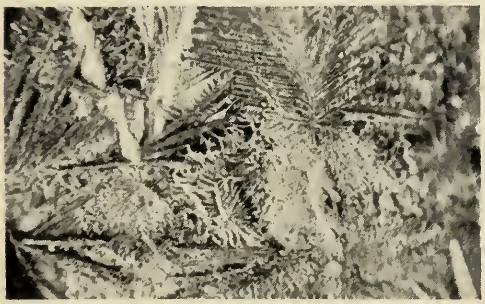
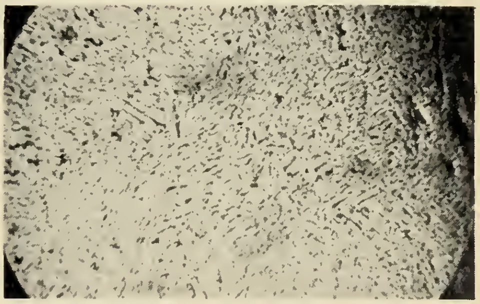


Fig. 45.

46% Cu. × *20 diams.* *v.*



f.c. furnace-cooled. *o.* oblique illumination. *v.* vertical illumination.

Fig. 46.

50% Cu. × *18 diams.* *v.*

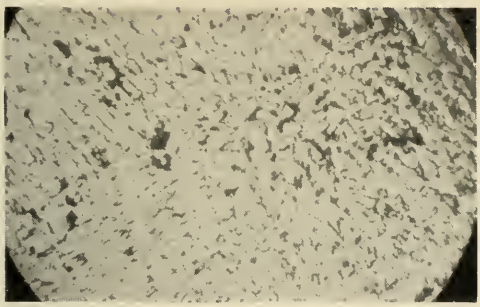


Fig. 47.

Quenched below Break 1, Fig. 1.

50% Cu. × *20 diams.* *v.*

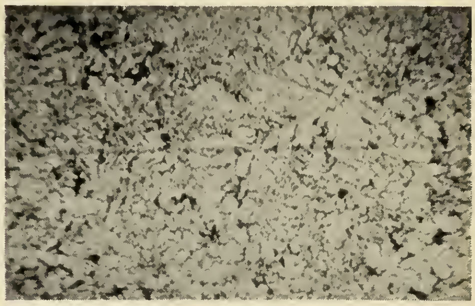


Fig. 48. *Quenched below Break 2.*

50% Cu. × *20 diams.* *v.*

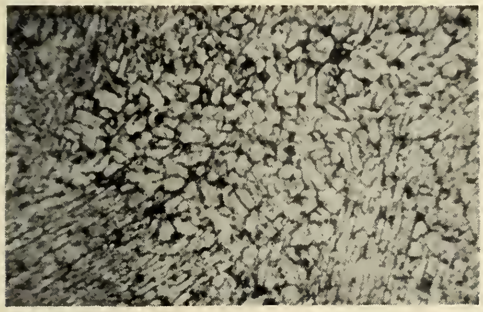


Fig. 49.

56% Cu. × *20 diams.* *v.*

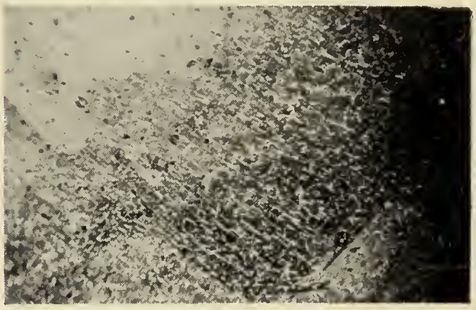


Fig. 50.

60% Cu, f.c. × *20 diams.* *v.*

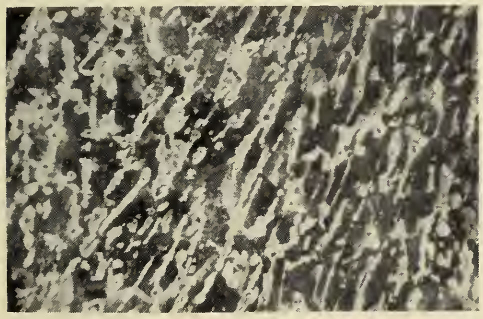


Fig. 51.

61·5% Cu, f.c. × *20 diams.* *o.*

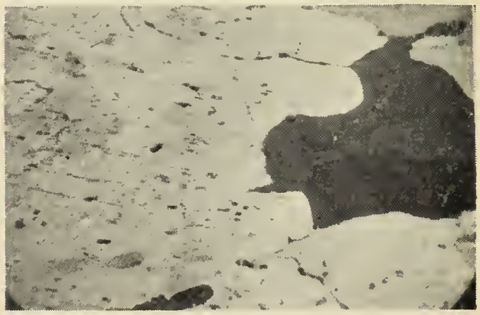


Fig. 52.

62·5% Cu, f.c. × *20 diams.* *v.*

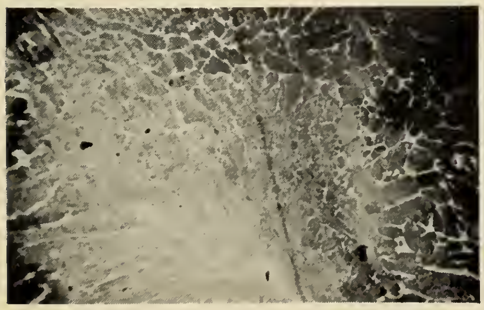


Fig. 53.

63% Cu, f.c. × *20 diams.* *v.*

f.c. furnace-cooled. *o.* oblique illumination. *v.* vertical illumination.

Fig. 54.

64% Cu, f.c. × *20 diams.* *v.*

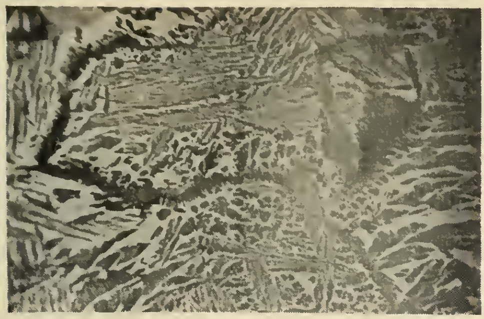


Fig. 55.

65% Cu, f.c. × *20 diams.* *v.*

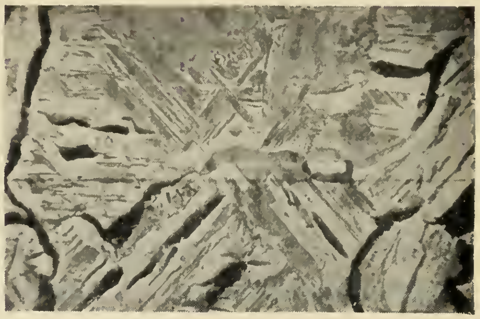


Fig. 56.

65% Cu, f.c. × *53 diams.* *v.*

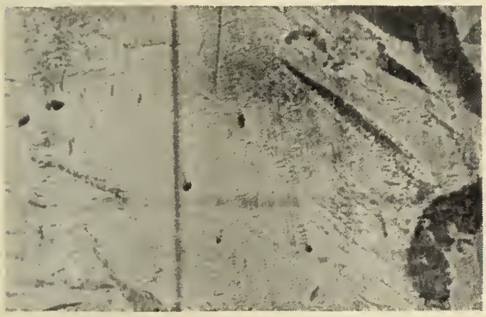


Fig. 57.

66% Cu, f.c. × *20 diams.* *v.*

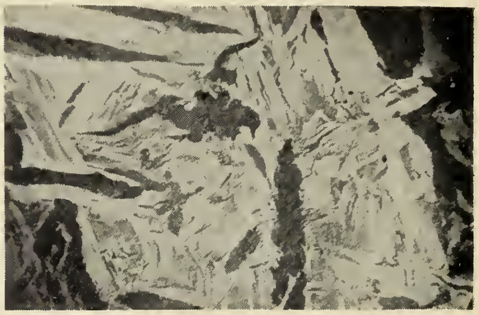


Fig. 58.

66% Cu. × *20 diams.* *v.*

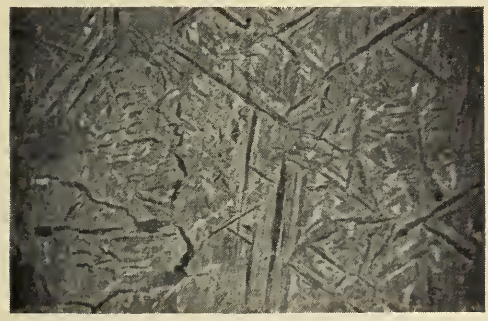


Fig. 59. *Quenched on Break 1.*

66% Cu. × *20 diams.* *v.*

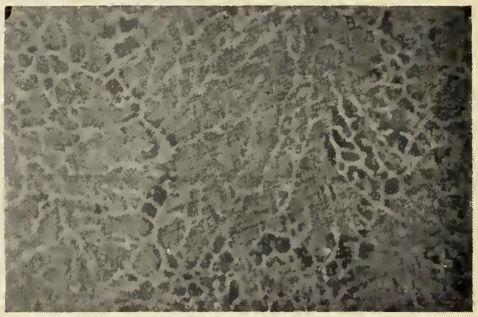


Fig. 60. *Quenched on Solidification.*

66% Cu. × *20 diams.* *v.*

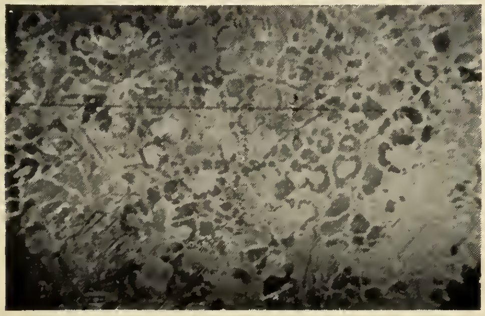
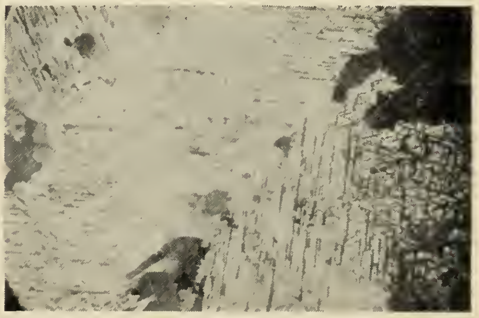


Fig. 61. *Quenched below Break 1.*

66% Cu. × *20 diams.* *v.*



f.c. furnace-cooled. *o.* oblique illumination. *v.* vertical illumination.

Fig. 62.

66% Cu. Quenched below Break 2.

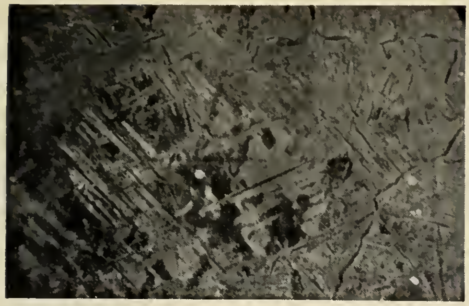


Fig. 63. *Cast on plate.*

66% Cu, Surface Section × 20 diams. v.

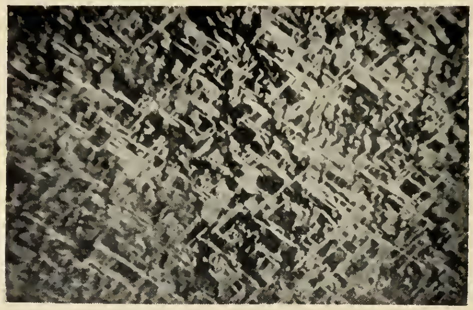


Fig. 64. *Ingot.*

66% Cu. Surface Section. × 20 diams. v.

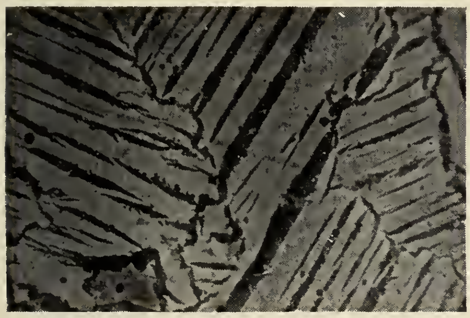


Fig. 65.

68·3% Cu, f.c. × 20 diams. v.

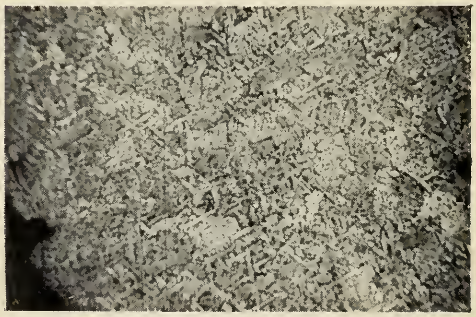


Fig. 66. *Cast on plate.*

68·3% Cu. × 20 diams. o.

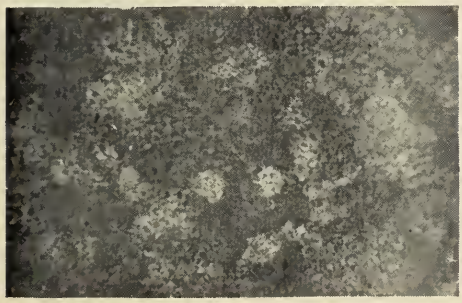


Fig. 67. *Ingot.*

68·3% Cu. × 20 diams. o.

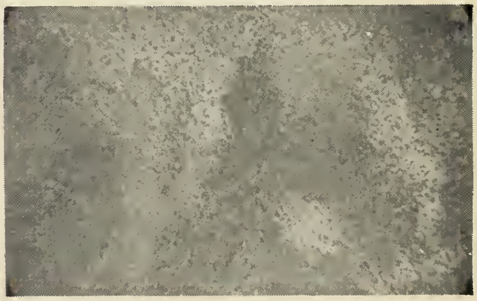


Fig. 68. *Quenched on Solidification.*

68·3% Cu. × 20 diams. v.

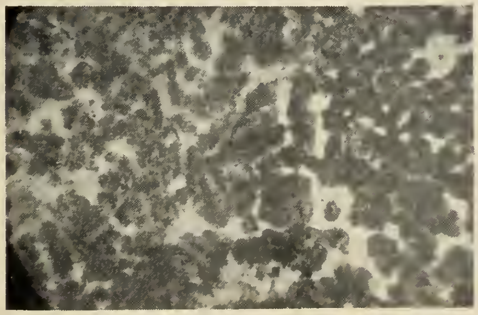
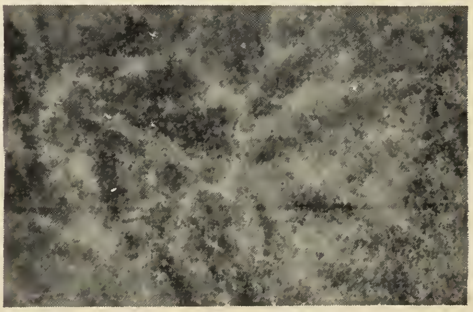


Fig. 69. *Quenched on Solidification.*

68·3% Cu. × 33 diams. v.



f.c. furnace-cooled. *o.* oblique illumination. *v.* vertical illumination.

Fig. 70.

72% Cu, f.c. × *20 diams* *v.*

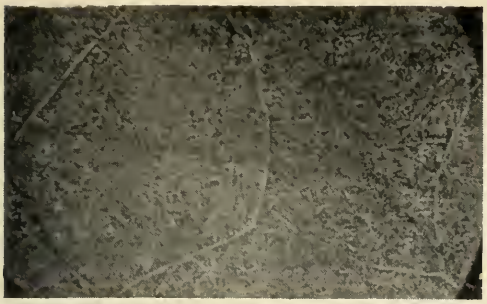


Fig. 71.

73% Cu, f.c. × *20 diams.* *v.*

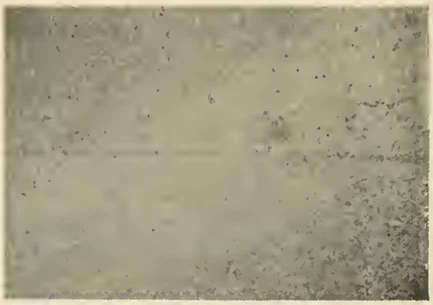


Fig. 72. *Surface Section.*

73% Cu. × *33 diams.* *v.*

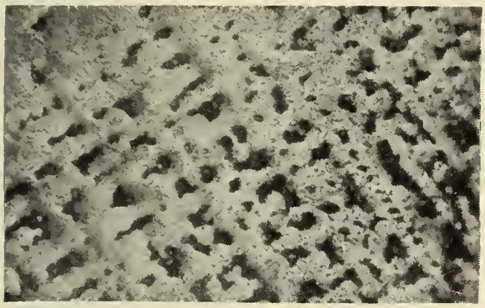


Fig. 73.

73% Cu. × *53 diams.* *v.*

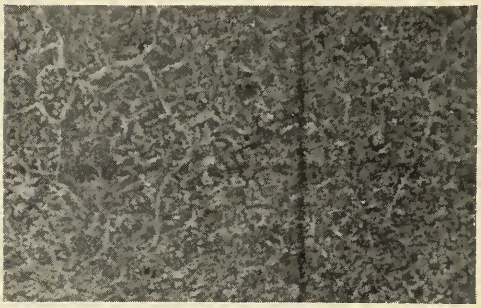


Fig. 74. *Quenched on Solidification.*

73% Cu. × *20 diams.* *v.*

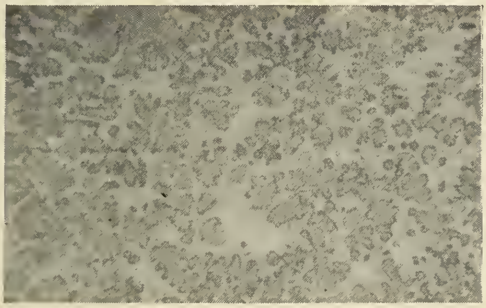


Fig. 75. *Quenched at 650° C.*

73% Cu. × *20 diams.* *v.*

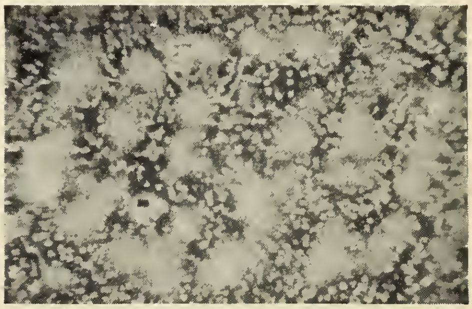


Fig. 76. *Quenched at 500° C.*

73% Cu.

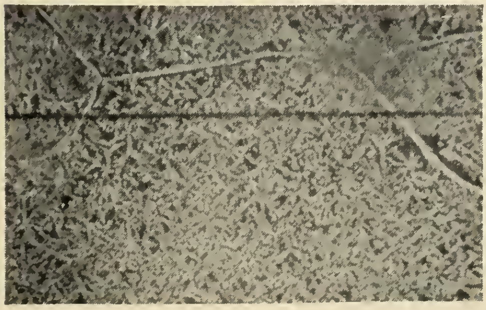
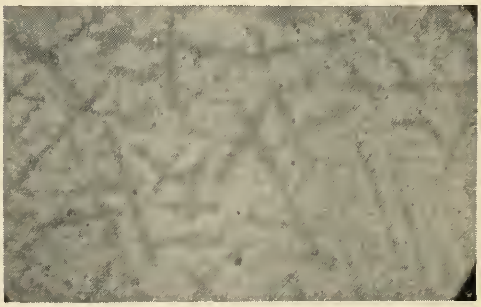


Fig. 77. *Cast. Vertical Section.*

73% Cu, Upper part. × *20 diams.* *v.*



f.c. furnace-cooled. *o.* oblique illumination. *v.* vertical illumination.

Fig. 78.
Reheated, Quenched, and Annealed.
73% Cu, f.c. × 20 diams. v.

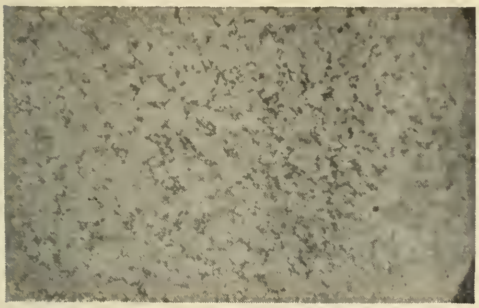


Fig. 79.
74% Cu, f.c. × 20 diams. o.

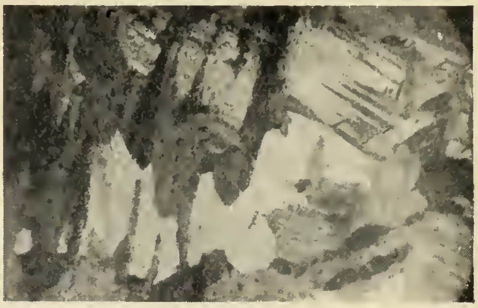


Fig. 80.
74% Cu, f.c. × 53 diams. v.

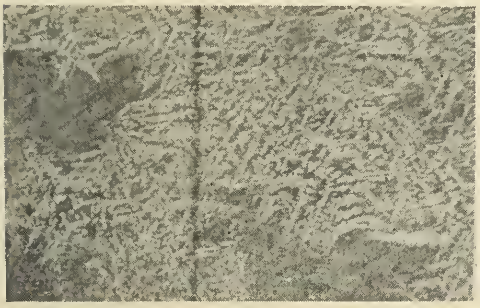


Fig. 81. *Cast Surface.*
75% Cu, f.c. × 20 diams. v.

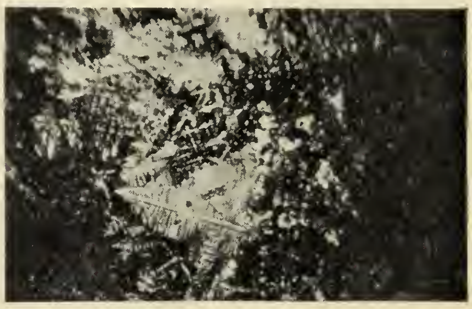


Fig. 82. *Cast. Surface Section.*
75% Cu. × 20 diams. v.

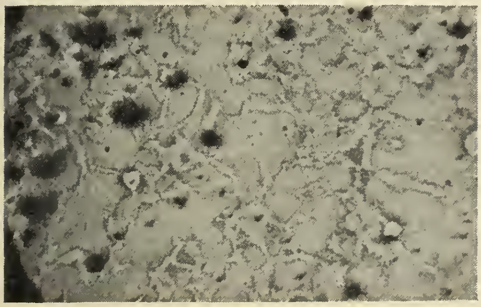


Fig. 83. *Reheated and Quenched.*
75% Cu, f.c. × 20 diams. v.

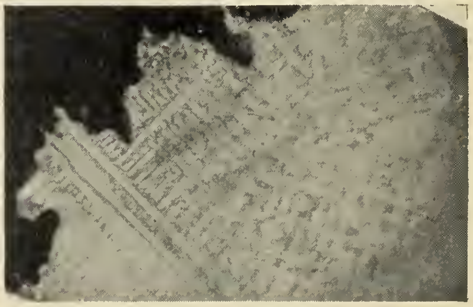


Fig. 84.
76% Cu, f.c. × 20 diams. v.

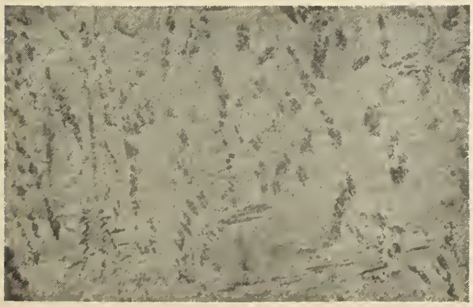


Fig. 85.
76% Cu, f.c. × 53 diams. v.

f.c. furnace-cooled. *o.* oblique illumination. *v.* vertical illumination.

Fig. 86. *Quenched at Solidification.*
76% Cu. × 20 diams. v.

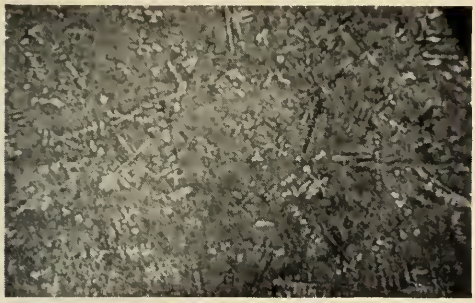


Fig. 87. *Reheated and Quenched.*
76% Cu, f.c. × 20 diams. v.

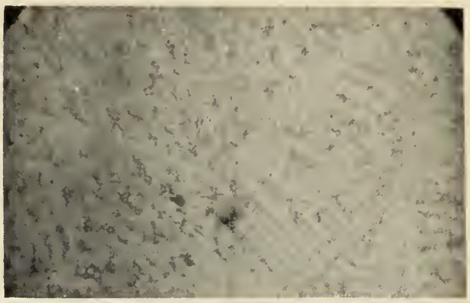


Fig. 88.
77% Cu, f.c. Surface. × 10 diams. o.

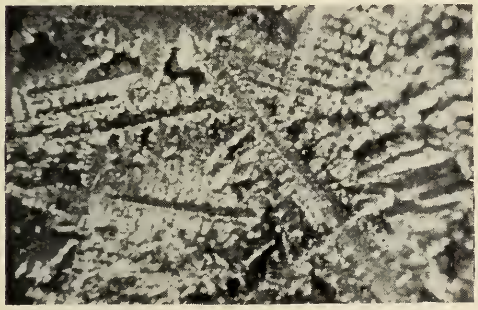


Fig. 89. *Surface Section.*
77% Cu, f.c. × 20 diams. v.

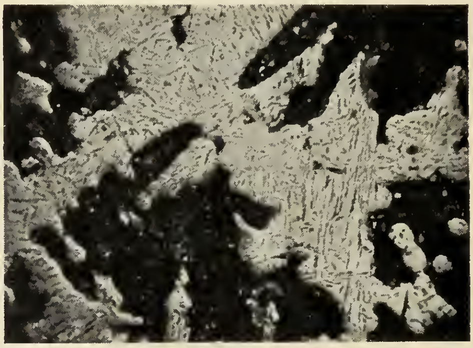


Fig. 90.
77% Cu. × 20 diams. o.

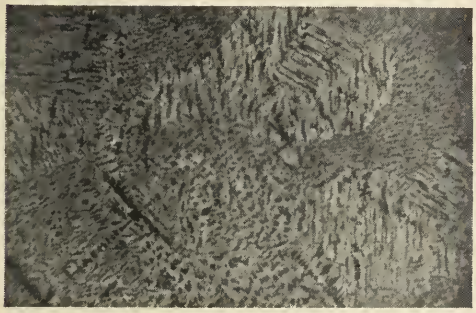


Fig. 91.
80% Cu. × 20 diams. v.

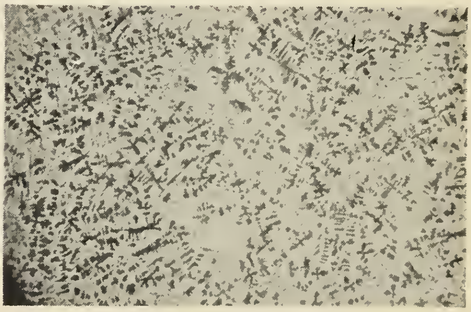


Fig. 92.
80% Cu. × 20 diams. v.

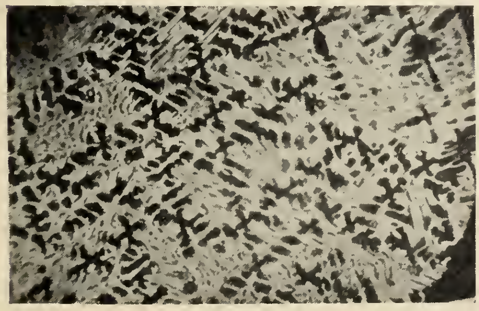
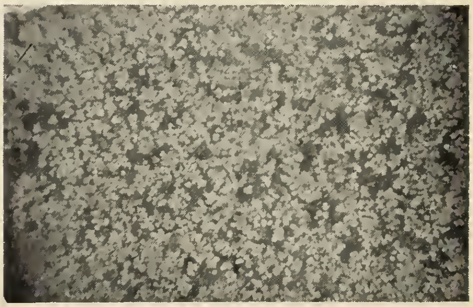


Fig. 93. *Quenched Liquid.*
80% Cu. × 20 diams. v.



f.c. furnace-cooled. *o.* oblique illumination. *v.* vertical illumination.

Fig. 94.
Quenched below Break 1.
80% Cu. × *20 diams.* *v.*

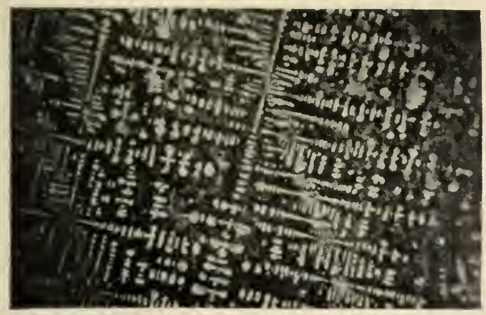


Fig. 95.
Quenched below Break 2.
80% Cu. × *20 diams.* *v.*

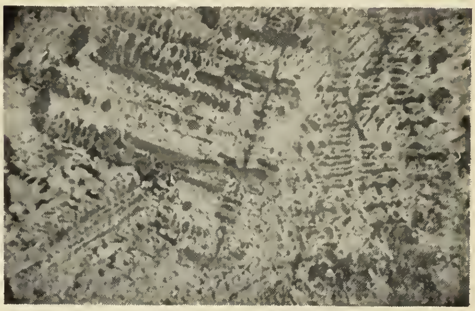


Fig. 96.
The same as Fig. 95. Centre.

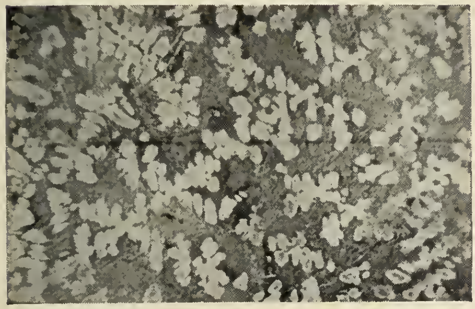


Fig. 97. *Surface Section.*
80% Cu. × *20 diams.* *v.*

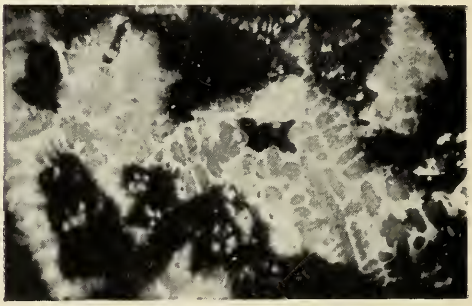


Fig. 98.
The same as Fig. 97.

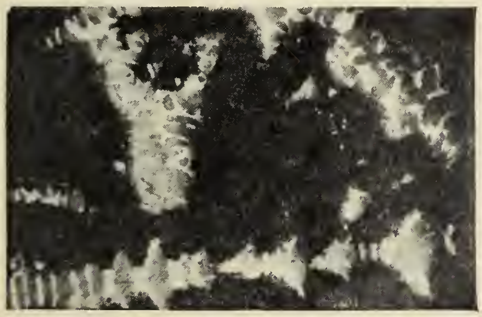


Fig. 99. *Cast. Vertical Section.*
80% Cu. × *20 diams.* *v.*

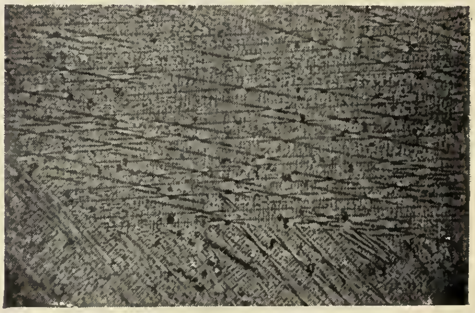


Fig. 100. *Cast and Annealed.*
80% Cu. × *20 diams.* *v.*

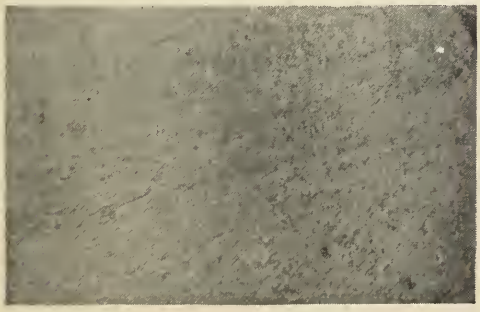
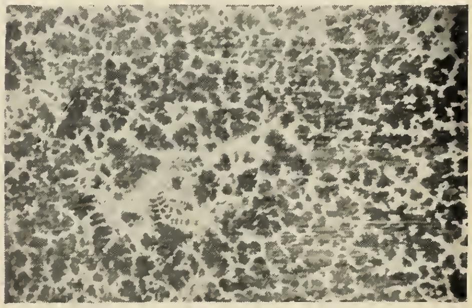


Fig. 101.
85% Cu. × *20 diams.* *v.*



f.c. furnace-cooled. *o.* oblique illumination. *v.* vertical illumination.

COPPER-TIN ALLOYS.

Plate 202.

Fig. 102.

85% Cu. × *53 diams.* *v.*

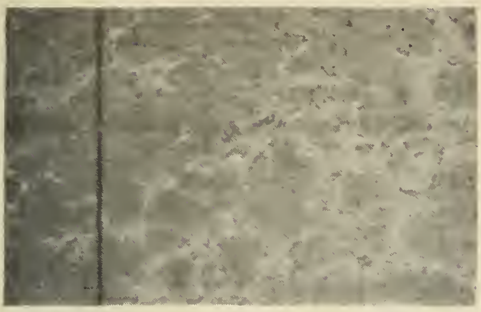


Fig. 103.

90% Cu. × *20 diams.* *v.*

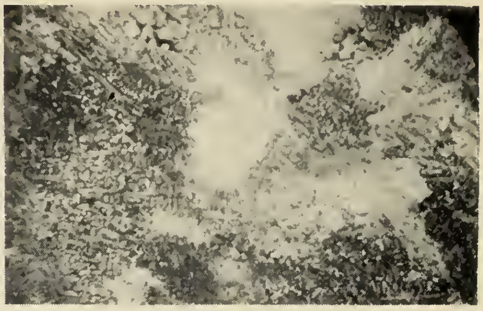


Fig. 104. *Surface Section.*

90% Cu. × *20 diams.* *v.*

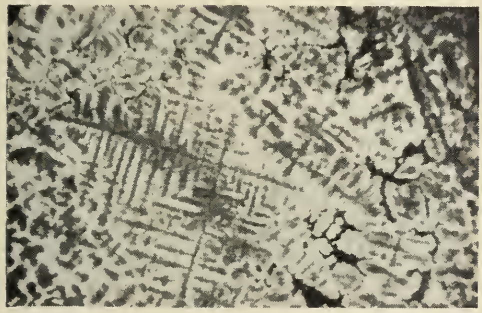


Fig. 105.

90% Cu. × *20 diams.* *v.*

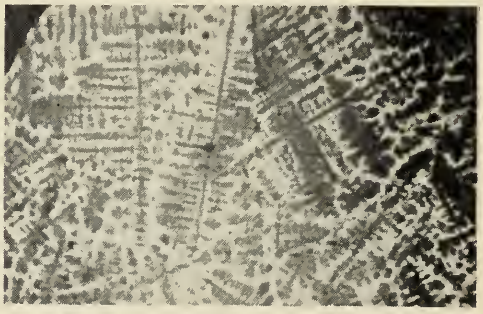


Fig. 106.

95% Cu. Surface. × *20 diams.* *o.*

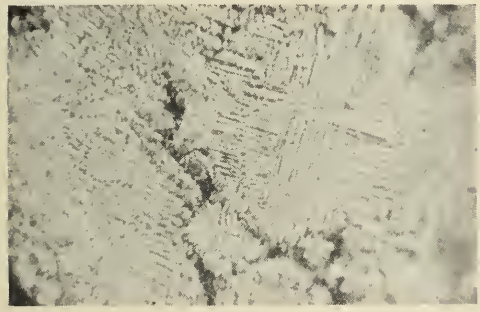


Fig. 107.

97·5% Cu. × *20 diams.* *v.*

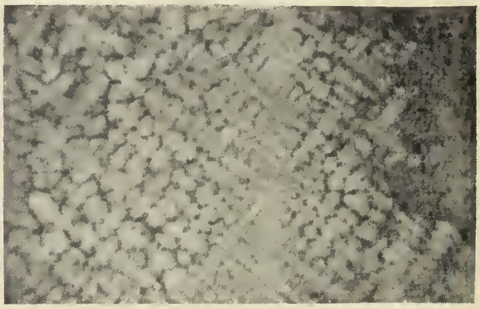


Fig. 108. *Top of Chilled Alloy.*

65% Cu, f.c. × *20 diams.* *v.*

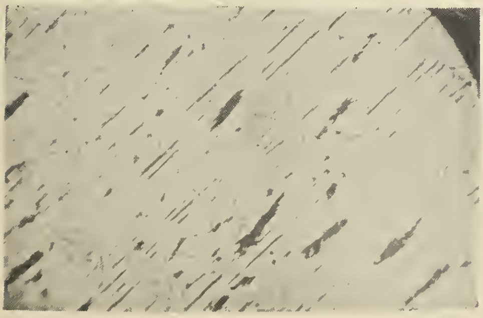
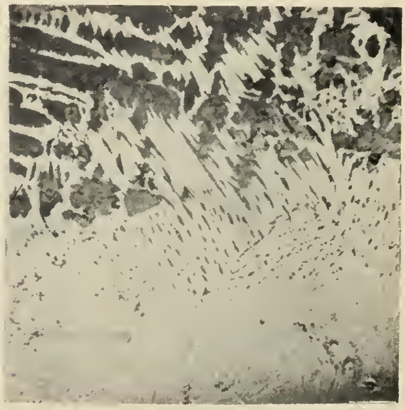


Fig. 109.

70-80% Cu, f.c. × *20 diams.* *v.*



f.c. furnace-cooled. *o.* oblique illumination. *v.* vertical illumination.

Mechanical Engineers 1901.

COPPER-TIN ALLOYS.

Fig. 111. *1% Cu, f.c.*

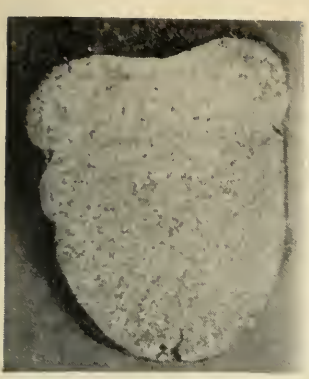


Fig. 112. *5% Cu, f.c.*

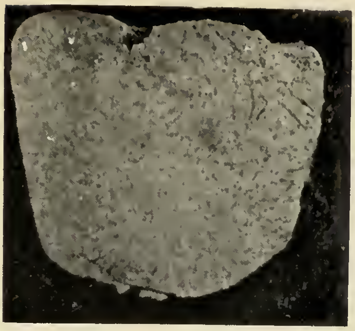


Fig. 113. *10% Cu, f.c.*

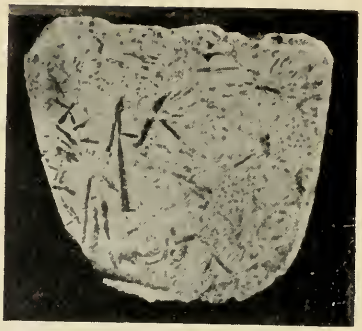


Fig. 114. *20% Cu, f.c.*

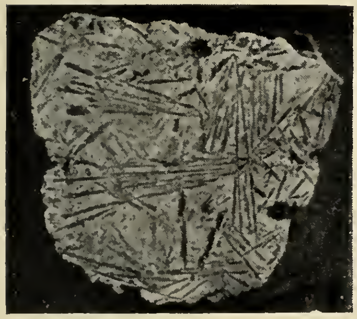


Fig. 115. *40% Cu.*

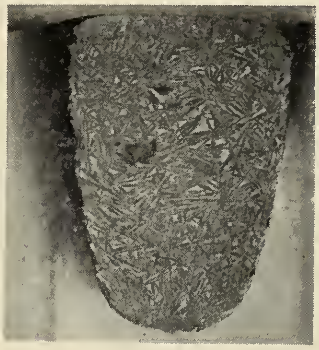


Fig. 116. *40% Cu, f.c.*

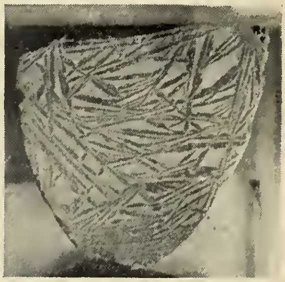


Fig. 117.
40% Cu. Horiz. Section.

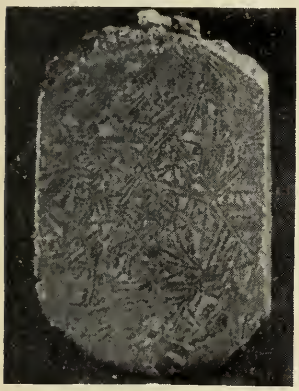


Fig. 118. *45% Cu, f.c.*

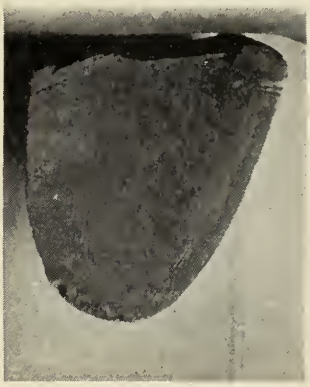
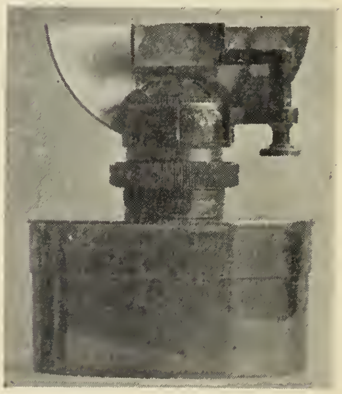


Fig. 119.
Beck Reflector, and Sorby Mirror.



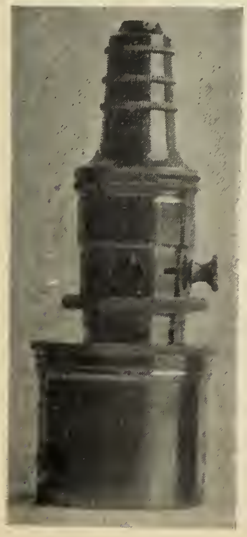
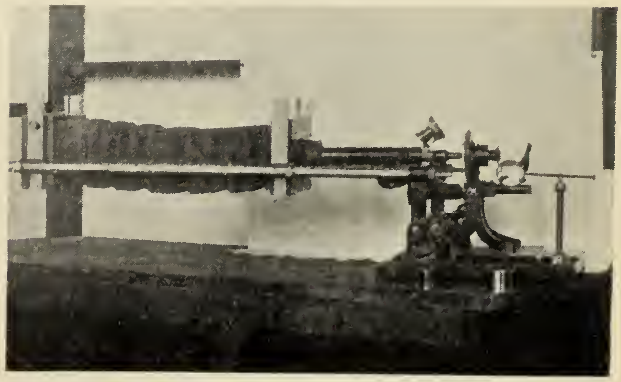


Fig. 120.
Beck Illuminator.

Fig. 121. *Camera and Microscope.*



f.c. furnace-cooled.

COPPER-TIN ALLOYS.

Plate 204.

(*Dr. T. K. Rose's remarks.*)

Fig. 122. *Crystals of $Sb\,Cu_3$.*
83·33% Sn. 11·11% Sb. and 5·5% Cu.

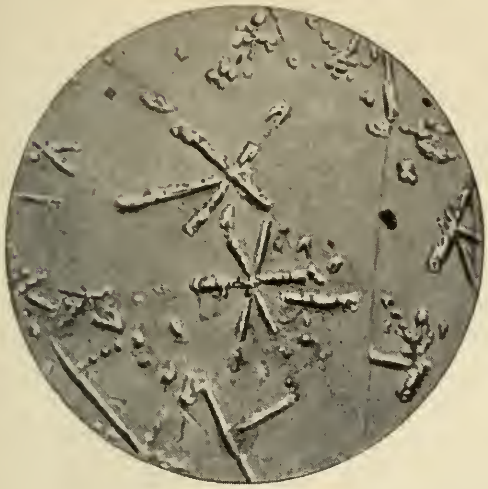
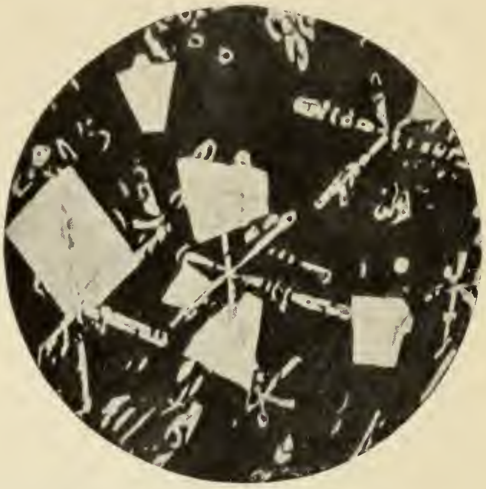


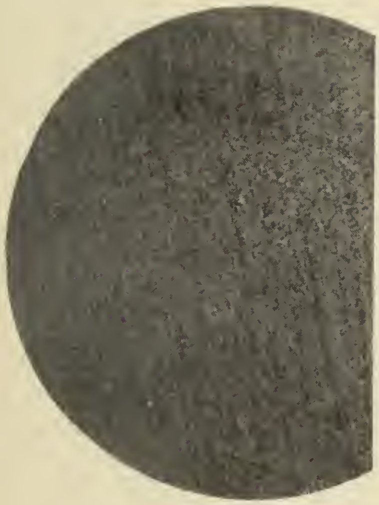
Fig. 123. *The same, etched with HCl.*
Stars of $Sn\,Cu_3$, Cubes Sb Sn.



(*Mr. Bertram Blount's communication.*)

Pure Copper, Electrolytically deposited.

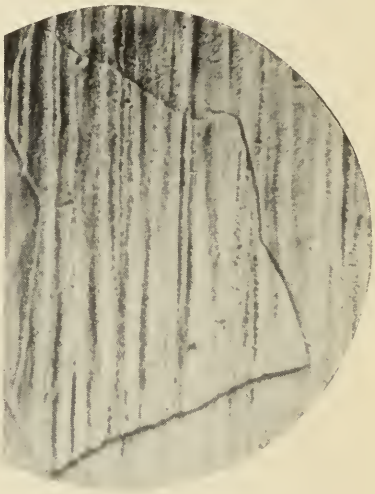
Fig. 124.
Long. Sectn. × 115 diams.



ANALYSIS.

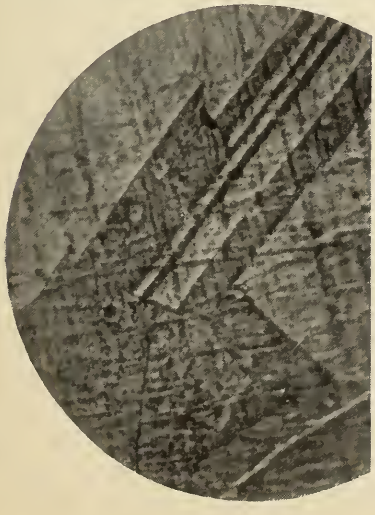
Cu.	99·961
As.	Nil.
Sb.	0·002
Sn.	Nil.
Pb.	Nil.
Bi.	Nil.
Fe.	0·005
Ni.	Nil.
S.	Trace
O.	0·025
	99·993

Fig. 125.
The same, fused. × 40 diams.



Commercial Copper.

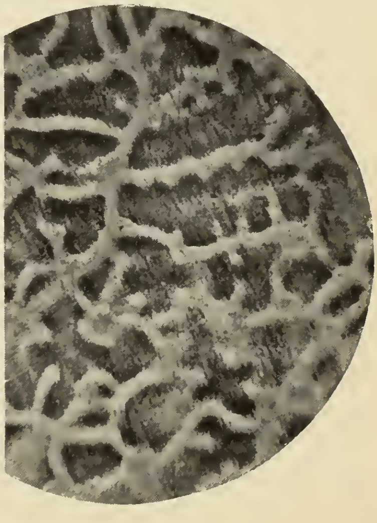
Fig. 126.
Long. Sectn. × 115 diams.



ANALYSIS.

Cu.	99·54
As.	0·12
Sb.	Trace
Pb.	0·17
Bi.	Trace
Fe.	Trace
Ni.	0 03
O.	0·15
	100·01

Fig. 127.
The same, fused. × 40 diams.



Mechanical Engineers 1901.

COPPER-TIN ALLOYS.

(*Mr. J. T. Milton's remarks.*)

Fig. 128. *Slowly cooled.*
White Metal. × *40 diams.*

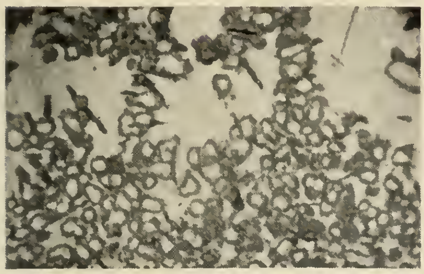


Fig. 129.
8·5% Cu. × *40 diams.*
Cast on chill. *Slowly cooled.*

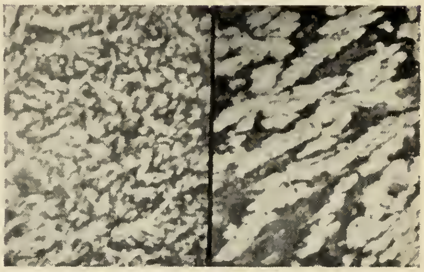


Fig. 130. *Slowly cooled.*
4% Cu. × *40 diams.*

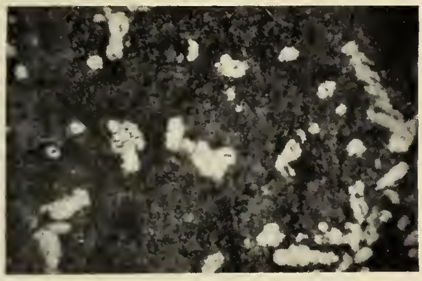


Fig. 131. *Slowly cooled.*
2% Cu. × *40 diams.*

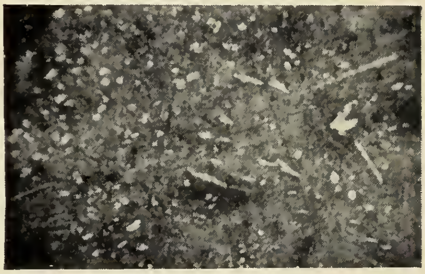


Fig. 132. *Slowly cooled.*
1% Cu. × *40 diams.*

Fig. 133. *Slowly cooled.*
·5% Cu. × *40 diams.*

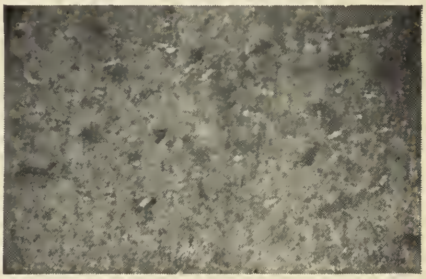


Fig. 134. *Slowly cooled.*
·25% Cu. × *40 diams.*

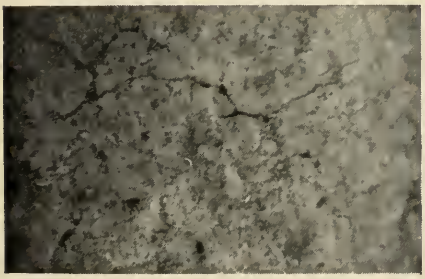
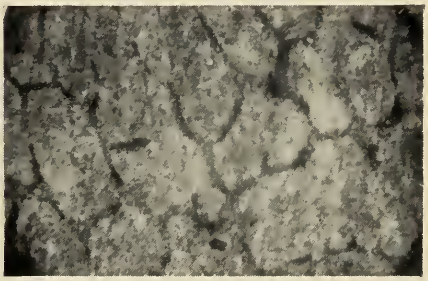


Fig. 135. *Slowly cooled.*
Sn. Deeply etched. × *40 diams.*



COPPER-TIN ALLOYS.

(Mr. J. T. Milton's remarks.)

Fig. 128. *Slowly cooled.*
White Metal. × 40 diams.

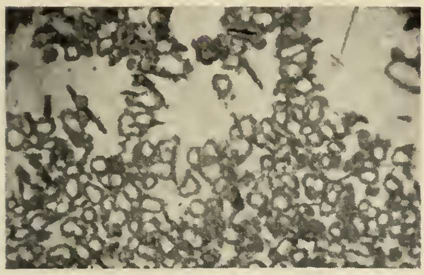


Fig. 129.
8·5% Cu. × 40 diams.
Cast on chill. Slowly cooled.

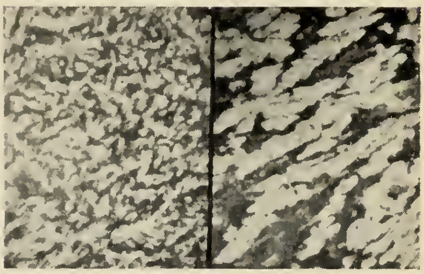


Fig. 130. *Slowly cooled.*
4% Cu. × 40 diams.

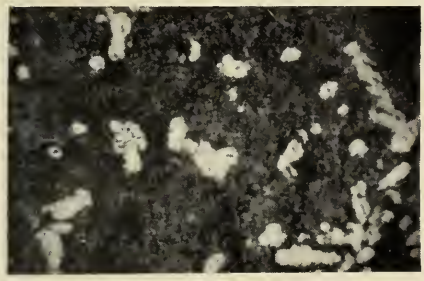


Fig. 131. *Slowly cooled.*
2% Cu. × 40 diams.

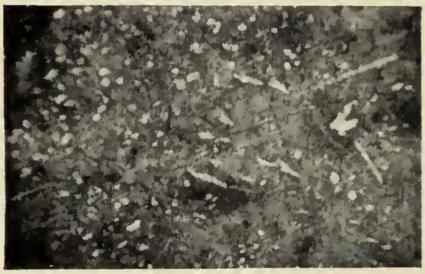


Fig. 132. *Slowly cooled.*
1% Cu. × 40 diams.

Fig. 133. *Slowly cooled.*
·5% Cu. × 40 diams.

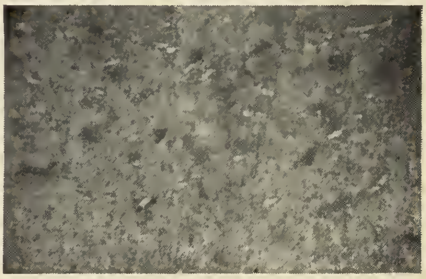


Fig. 134. *Slowly cooled.*
·25% Cu. × 40 diams.

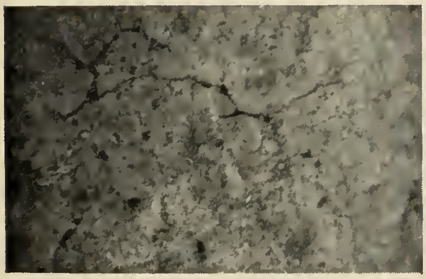
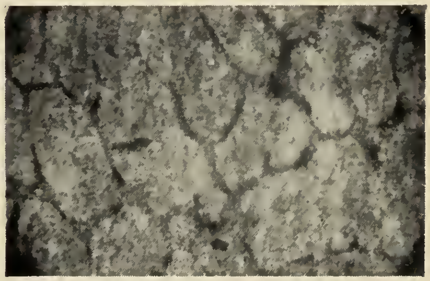


Fig. 135. *Slowly cooled.*
Sn. Deeply etched. × 40 diams.



COPPER-TIN ALLOYS.

(Appendix to Messrs Heycock and Neville's remarks.)

Fig. 137.

30% Sn. Chilled at 740° C. × 50 diams.

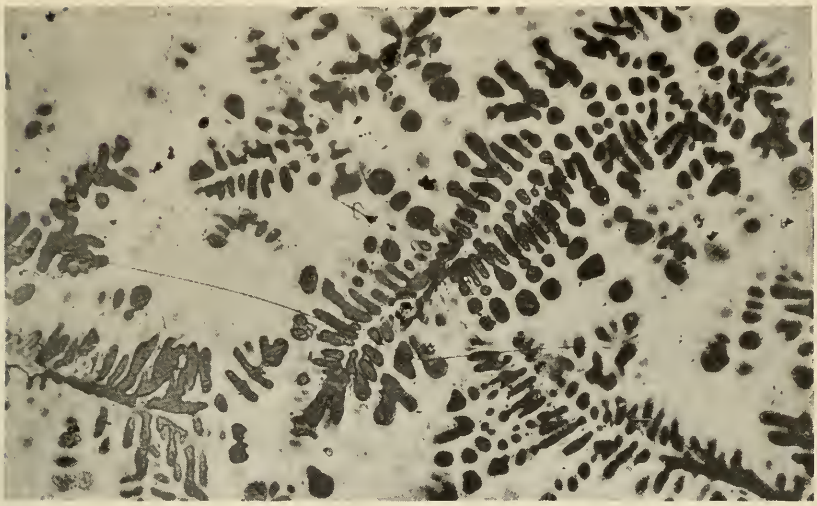
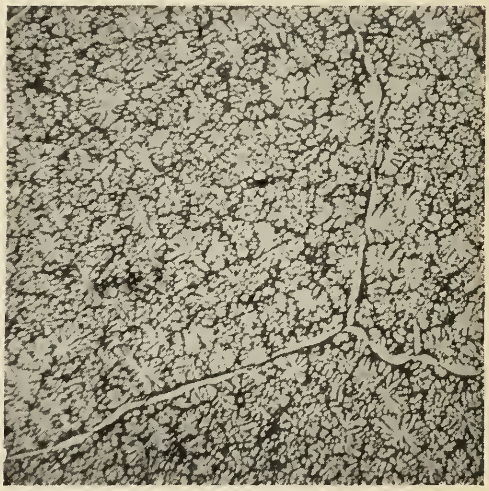


Fig 138. *Chilled at 630° C.*

30% Sn. × 50 diams.

Fig. 139. *Chilled at 500° C.*

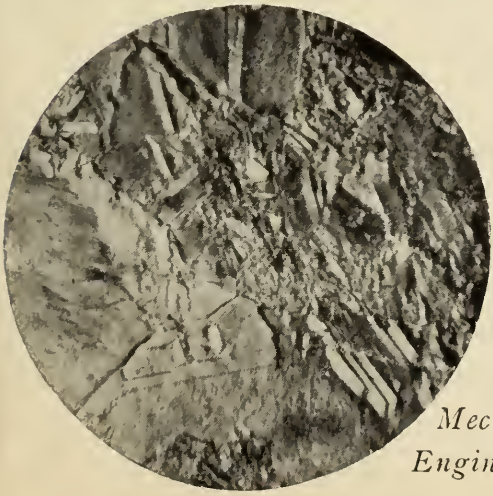
30% Sn. × 50 diams.



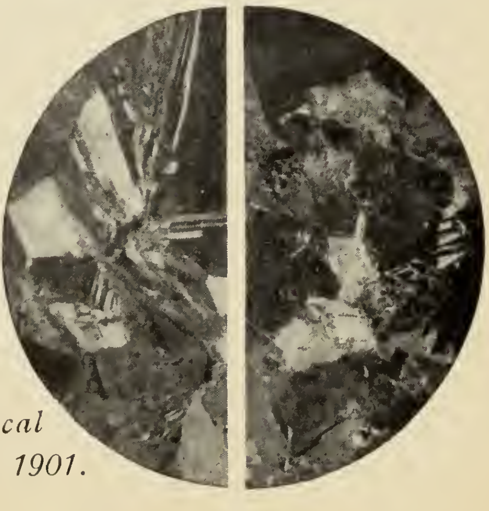
(Author's reply.)

Electro-copper direct from Vats. Etched by HNO_3.

99·9% Cu. Fig. 141. *× 33 diams. o.*



99·9% Cu. Fig. 142. *× 33. v.*



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